5-30-2013

An Investigation into the Efficacy of Alarm Fatigue Reduction Strategies

Jeffrey Thomas Peterson
University of Connecticut - Storrs, j.t.peterson01@gmail.com

An Investigation into the Efficacy of Alarm Fatigue Reduction Strategies

Jeffrey Peterson

B.S., University of Connecticut, 2011

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the

University of Connecticut

2013

APPROVAL PAGE

Masters of Science Thesis

An Investigation into the Efficacy of Alarm Fatigue Reduction Strategies

Presented by

Jeffrey Peterson, B.S.

Major Advisor ____
John Enderle, Ph.D.

Associate Advisor ____
Frank Painter, M.S.

Associate Advisor ____
Quing Zhu, Ph.D.

Associate Advisor ____
Terri Crofts, M.S.

University of Connecticut

2013

Acknowledgements

This project and thesis would simply not have been occurred without the talents of Terri Crofts, Urania Michael, Dr. Robert Klugman, Lisa Gillum and everyone who I was fortunate enough to work with at UMass. No one walks alone on project of this scale and complexity. I would have certainly lost my way without the guidance and knowledge of those around me.

Thank you to everyone in the Biomedical Engineering department for putting up with my continuous barrage of questions. The knowledge and experience I have been privileged enough to acquire these last two years was not drawn from thin air but rather painstakingly and meticulously delivered to me by others throughout the duration of my internship. A special thanks to Terri Crofts and Urania Michael for their support throughout this project. Thank you to every one of the UMass BMETs, including Rob Beatty who received the lion's share of my technology questions. Thanks to my co-intern Lily Zamora. I would not have been able to accomplish anything without the constant assistance of my managers Shelley Sartini, Joe Williams, Chirag Pujary and Joe Wagner. Thank you all for helping me grow professionally these last two years. I am forever grateful.

I would like to thank UMass Memorial Medical Center for sponsoring my studies and internship as well as providing me with the opportunity to apply my knowledge toward a challenging problem like alarm hazards. The entire UMass healthcare system impresses me daily with their professionalism, talent and unwavering, resolute desire to care for others.

A special thank you to Frank Painter for the comprehensive clinical engineering education you have provided me. It's difficult for me to pretend a simple thank you is sufficient for providing me with the educational foundation of my career, but it will have to suffice for now. I would also like to thank my academic advisors Dr. John Enderle and Dr. Quing Zhu for their support and assistance. Lastly a personal thank you to my friends, girlfriend and family.

Table of Contents

Table of Figures

Table of Tables

Abstract

Modern hospitals are plagued by excessive alarms generated by patient monitoring technologies with very high sensitivity and low selectivity leading to high rates of false and clinically irrelevant alarms. Studies have shown patient monitoring systems to have a false and/or clinically insignificant alarm rate of 80%-99%. Multiple studies have shown that these false and clinically irrelevant alarm rates can negatively impact patient care and lead to "alarm fatigue". Alarm fatigue is when a nurse or clinician is continuously overloaded with alarm information with various degrees of accuracy; the result is a selective and spontaneous alarm response pattern and distrust in the accuracy, credibility and reliability of the source. Alarm hazards have been named the number one health technology hazard by ECRI Institute for 2012 and 2013. A review by the FDA revealed 566 alarm related deaths in a recent four year period.

At a large, teaching hospital in Massachusetts, a quantitative, database driven approach to alarm management was adopted in the acute care and medical/surgical environment with the intent to identify and implement technological, clinical, educational, and workflow practice changes to curtail excessive alarming. A database representing a subset of the total alarm burden from patient monitoring devices was analyzed. The measured subset revealed a combined total of 31.5 arrhythmia and pulse oximetry alarms per patient per day (alarms/pt/day) (SD = 50.4, median = 5, total = 948,262). Observations determined the database contained 35%-55% of the total alarm burden.

Two countermeasures were successfully deployed, two were deployed with inconclusive results and four were developed and not deployed. Unlatching yellow SpO_2 alarms successfully achieved a reduction of ~6.5 min/pt/day of clinically irrelevant alarm noise. A nursing reeducation of telemetry best practices conducted in parallel with a reconfiguration of the alarm distribution to

page all alarms to every nurse's phone successfully achieved a reduction in the raw count of reminder alarms per day and a reduction in battery related in-op alarms from 9.8 alarms/pt/day to 7.0 alarms/pt/day. Implementing remote suspension of alarms from the telemetry pack had no impact on the alarm count. A daily electrode change in a neuro-ICU had no marked reduction in alarm counts. New default parameters for adult cardiac telemetry were developed and predicted to eliminate an estimated 12.8 alarms/pt/day. An algorithm for selection of alternate SpO_2 site monitoring was developed. A new order set specifying indications for the initiation and discontinuation of adult cardiac telemetry was developed to remove an estimated 35% of patients from telemetry who were not indicated for use. A new order set for SpO_2 monitoring was planned to enable SpO_2 monitoring to be conducted without ECG monitoring.

The result of this ongoing effort was a reduction in the number and duration of clinically irrelevant, non-actionable alarms generated and a gradual shift in the culture surrounding monitoring alarms. The work conducted will serve as a roadmap for future process improvement work with patient monitoring systems.

1 Introduction

Cardiac telemetry monitors found in every modern hospital generate hundreds of physiologic and technical alarms daily, the majority of which are false or clinically irrelevant, leading to alarm fatigue and alarm desensitization. Alarm hazards, including alarm fatigue, are the number one healthcare technology hazard in 2012 and 2013 [1] [2]. The modern healthcare environment generates a monumental amount of patient monitoring alarms. Ideally, each alarm signals the presence of a condition that should require the immediate attention of a caretaker in order to maintain the patient's safety. In reality, the alarms generated are not always pertinent to the patient's safety. There are a multitude of conditions that can result in the alarm being irrelevant to patient safety. For example, a medical/surgical patient stands to use the bathroom and experiences a momentary increase in heart rate, generating a high heart rate alarm. The alarm requires no intervention and bears no relevance on the patient's safety, but is announced via the same communication channels that a true, dangerous rise in heart rate alarm is announced. Repeated, frequent occurrences of these irrelevant alarms can result in a dangerous phenomenon termed alarm fatigue. This thesis aims to identify specific areas for improvement in the patient monitoring alarm system and to develop and implement countermeasures to minimize the frequency and duration of non-actionable, clinically irrelevant alarms.

1.1 Background

Patient monitoring devices are intended to alert caregivers of degradation in a patient's physiological state. These devices are used to alert nurses and clinicians that an intervention and action is needed. Medical device manufacturers design monitoring equipment with patient safety at the foremost of their designs. Each patient monitoring alarm was purposefully designed to be as sensitive as possible, as not to miss a single true event, i.e. zero false negative alarms. This practice resulted in patient monitoring systems with high sensitivity, low specificity alarms. Patient monitors have been shown to have a sensitivity of 97% and a specificity of 58% with a positive predictive value of 27% and a negative predictive value of 99% [3]. Patient monitoring technologies typically produce an extremely large quantity of alarms but a relatively small amount of true alarms.

During a Stanford University Medical Center alarm study, conducted over a two-month period more than 318,000 cardiac arrhythmia monitor alarm signals went off in six units with 154 beds, which produced a burden of 883 alarm signals per unit per day. 43% of alarm conditions indicated non-critical, and “generally non-actionable” events, 38% of alarm conditions indicated premature ventricular complexes (PVCs), which are not treated, and only 3.6% of alarm conditions indicated true critical events [4]. Similarly, a study of a 79 bed community hospital found 34% of red alarms to be true and 63% of high priority or yellow alarms to be true. Patient monitoring is undoubtedly a major source of frustration with staff and presents a risk to the safety of patients [5].

Alarms can be generally classified into three separate categories: true, false and nuisance. A true alarm indicates an adverse event which requires prompt action be taken by the caregiver to ensure the safety of the patient. A false alarm displays that an adverse event is occurring, but the patient is not experiencing the physiological or technological condition indicated by the alarm. A false alarm may be a misinterpretation of a different alarm worthy condition, resulting in the severity of the alarm presented to be different from reality. A nuisance alarm is a true, accurate alarm that has no relevance to the patient’s safety [6]. There are situations were a true alarm may be clinically relevant but no action is required, e.g. a cardiac patient suffering from repeated non-life threatening arrhythmias. In this case, the presence and frequency of the arrhythmia is used to monitor the patient's condition, not to alert the caregiver of action that needs to be taken. Clinically irrelevant, non-actionable nuisance alarms distract caregivers from true alarms and are the source of alarm fatigue and alarm desensitization.

1.2 Alarm Fatigue

Alarm fatigue occurs when an individual is continuously overloaded with alarm information with various degrees of accuracy; the result is a selective and spontaneous alarm response pattern and distrust in the accuracy, credibility and reliability of the source. Alarm fatigue can result in a number of undesired behaviors by caregivers. An overabundance of alarms can cause the user to blend their perception of a single alarm into background noise, known as alarm desensitization [7] [8].

A common result of alarm fatigue is a delayed response time to an alarm or a missed alarm altogether. Alarm fatigue may also lead to staff improperly changing alarm parameters and settings to a level outside a safe and appropriate range, turning the volume of an alarm down to a level where it may become inaudible, or staff not adhering to a facility's alarm policies [1].

In the modern healthcare environment, the amount of devices used to monitor a patient is increasing which, in turn, is increasing the number of alarms a patient is capable of generating [2]. The staff responsible for patient care has to adapt to this modern care setting, as each device attempts to alert them of a problem in its own way.

Alarm fatigue can affect any person who uses a medical device to aid in administering care to a patient. The most common sources of alarm fatigue are found in hospital rooms with multiple devices. A typical patient room in an intensive care unit may have a multi-parameter physiologic monitor, multiple infusion pumps, a ventilator, and other accessory devices like a sequential compression device and bed/chair alarm, all of which are capable of generating an alarm. A patient in an acute care telemetry environment may have a telemetry pack with electrocardiogram and blood oxygen saturation monitoring capabilities, as well as an infusion device, noninvasive blood pressure, nurse call system, bed and chair alarm, and other accessory devices that are capable of alarming. The sources of alarms are so abundant that simply determining the source of an alarm can be a challenge within itself [9].

1.3 Impact of Alarm Fatigue

According to the ECRI Institute, alarm fatigue is ranked the number one healthcare technology hazard for 2012 and 2013 [2]. Adverse events resulting from alarm fatigue and alarm desensitization have been frequently published by newspapers making alarm fatigue a very public concern [10] [11] [12] [13]. A national survey of 3454 healthcare professionals, mostly nurses and respiratory therapists, conducted by the Healthcare Technology Foundation concluded that nuisance alarms occur frequently with 76% agreement and also concluded that nuisance alarms disrupt patient care with 71% agreement [9].

Alarm fatigue related deaths are notoriously under reported. A review of the FDA's Manufacturer and User Facility Device Experience (MAUDE) database reveals 566 deaths between 2005 and 2008 that directly mention alarms [14]. A review of the Joint Commission's Sentinel Event database, which is widely believed to be under reported due to the voluntary nature of the reports, includes reports of 98 alarm related events, 80 resulted in death, 13 in permanent loss of function, and five in unexpected additional care or extended stay between January 2009 and June 2012 [15]. From June 2004 to December 2008, there were 194 incidents and serious events, including 12 deaths, reported to the Pennsylvania Patient Safety Authority associated with cardiac telemetry [16].

1.4 Examples of Previous Alarm Fatigue Reduction Results

An alarm fatigue reduction project at Johns Hopkins Hospital created a task force to reduce the number of non-actionable, clinically irrelevant alarms. The project implemented improvements such as a daily electrode lead change for all patients. Additionally, clinicians redefined the default parameters to actionable levels, instructors trained every nurse on individualizing a patient's alarm settings and a policy defined clear accountability for alarm response. The initiatives reduced the total number of alarm conditions and signals from monitors hospital-wide, with a 43% reduction in high priority alarm conditions during a pilot period, a 47% reduction in alarms conditions/bed/day in two pilot studies and a 24%-74% reduction of alarm from a default parameter change in two ICUs [17].

An alarm fatigue reduction project at Beth Israel Deaconess Medical Center realized a number of quantitative and qualitative results including a 30% overall decrease in alarm signals, a decrease in response time for critical alarm signals from an average of 45 seconds to 10-15 seconds, and a decrease in the response time for leads off alarms from three minutes to between one and two minutes. Staff also implemented a daily electrode lead change as advocated by John Hopkins Hospital, redefined default parameters to actionable levels and provided training on continuous customization of the monitor settings [18].

1.5 Goals of Thesis

The intention of the study had the ultimate goal of was to improve patient safety by reducing caretaker exposure to excessive alarming, while subsequently reducing the risk of alarm fatigue and alarm desensitization. Reducing the risk of alarm fatigue would be accomplished by eliminating as much alarm "noise" as possible. Increasing the ratio of true alarm "signal" to false and clinical irrelevant, non-actionable alarm "noise" would minimize the risk of alarm fatigue. The strategy employed to decrease the noise was to decrease the total number of alarms generated and decrease the duration of all alarms. This was accomplished by process improvement initiatives that aimed to find technological and clinical changes.

In addition to technological and clinical changes, a general culture change was desired. Changing the mentality behind alarm management would resolve problems of conflicting incentives around telemetry utilization, inconsistent alarm response expectations, nondescript alarm distribution-resolution strategies and non-standardized and conflicting practice and policy. This thesis intended on implementing significant improvements to the practices around cardiac telemetry using a standardized process improvement methodology.

2 Methods

The study was conducted at a large teaching hospital in the Critical Care (non-ICU, non-Step-Down) environment. The purpose of this study was to reduce the number of clinically irrelevant non-actionable alarms in an effort to minimize the effects of alarm fatigue and its associated adverse effects. This was accomplished by creating and maintaining a database of all recorded alarms and continuously analyzing it in order to identify alarms that potentially contribute to alarm fatigue. Alarms identified as potential contributors to alarm fatigue were then subjected to lean process improvement techniques. Process improvement facilitated the creation and implementation of countermeasures to reduce the observed high alarm frequencies and durations. The alarm database was analyzed to quantify the efficacy of each countermeasure.

2.1 Alarm System Description

The patient monitoring system used in the study was a standard critical care telemetry patient monitoring system (Philips Healthcare™ – IntelliVue™ Telemetry Patient Monitoring, M4841A and M3155, 125Hz 8 bit). The telemetry monitoring devices were distributed throughout the facility. The distribution can be seen in Table 2-1.

The patient monitoring system measured ECG and SpO_2. The system was capable of announcing critical and high priority alarms. Critical alarms included lethal arrhythmias such as extreme high and low heart rate, ventricular tachycardia and asystole, as well as extreme oxygen desaturation. High priority alarms included high and low heart rate, low oxygen saturation, pacer not paced, pacer not captured, pause, irregular heart rate, non-sustained ventricular tachycardia, and premature ventricular contraction (PVC) arrhythmias like pair PVC, run PVC, PVC rate, multiform PVC, ventricular rhythm. The current alarms generated and the associated alarm settings are displayed in Table 7-1 in the appendix.

Table 2-1   Telemetry Monitor Distribution

Department	Number of Telemetry Devices	Number of Beds
Department 1	24	28
Department 2	24	26
Department 3	12	17
Department 4	12	24
Department 5	12	26
Department 6	24	28
Department 7	24	28
Department 8	20	38
Department 9	15	25
Department 10	16	31
Department 11	17	34
Department 12	16	26
Department 13	16	28
Department 14	8	27
Grand Total	**240**	**382**

2.2 Alarm Distribution

The alarms were distributed to nurses and clinicians using a variety of methods in order to ensure caretakers were provided with the right information at the right time. Alarms were distributed via audible and visual methods including central stations, remote displays (clients), ceiling mounted hallway marquee signs, and cell phone paging. Audible alarm tones were broadcasted from central stations and marquee signs for all alarms. The audible alarm tones varied based on the criticality of the alarm type with a higher pitch, higher volume for the critical red alarms. This is a standard functionality provided by the patient monitoring system. Waveforms were visible from the central stations located in the nurse station and remote display monitors located along the hallways. Alarms were also distributed using Philips Emergin™, a secondary alarm notification middleware system. Emergin™ was used to distribute alarms to marquee signs located along the hallway ceilings and to nurse cell phones via text messages. Alarm text messages are paged to each nurse based on their patient assignments. Although all alarms are announced via visual message and an audible tone from the central stations and clients, only a subset of alarms are sent to the marquee signs and nurses phones. All critical, red alarms were distributed using all methods. All high priority, yellow alarms were distributed using all methods except high and low heart rate, pair PVC, run PVC, R-on-T PVC, ventricular bigeminy, ventricular trigeminy, PVC Rate, multiform PVC, pause, and irregular heart rate, which were not recorded by Emergin™ and therefore not paged to cell phones or announced via hallway marque signs.

2.3 Alarm Database Creation

The approach used to reduce alarm fatigue required a database of alarms for quantitative analysis to highlight areas of improvement. To accomplish this task, the alarm activity log from a middleware alarm distribution product, Emergin™ Orchestrator, was used. The format of this log was a comma separated value spreadsheet with a single column containing the recorded information about each alarm and a single column for a date and time stamp, as seen in the appendix. The original format of this information was not usable for effective data analysis. Google Refine™, a data manipulation application, was used to intelligently parse the log into a usable format. The parsing and manipulation was accomplished using Google Refine™ controls, including Java regular expressions. A sample of the output of Google Refine™ is shown in the appendix. The output spreadsheet format was used for the alarm database analysis.

Table 2-2 Alarm Types Recorded in Database

Paged and Recorded in Database	Critical	*** ASYSTOLE
		*** V-FIB/TACH
		*** V-TACH
		***TACHY
		***BRADY
		*** DESAT
	High Priority	** SpO2T
		* NON-SUSTAIN VT
		* VENT RHYTHM
		* MISSED BEAT
		* PACER NOT CAPT
		* PACER NOT PACE
		* MISSED BEAT
		* PAUSE
		* SVT
	In-Op	ECG LEADS OFF
		NO SIGNAL
		REPLACE BATTERY T
		BATTERY LOW T
		!!!REPLACE BATT. T
NOT Paged or Recorded in Database	High Priority	* HR High
		* HR Low
		* RUN PVCs
		* PAIR PVCs
		* R-ON-T PVC
		* VENT BIGEMINY
		* VENT TRIGEMINY
		* PVCs > 10/min
		* MULTIFORM PVCs
		* IRREGULAR HR

The activity log of Emergin™ Orchestrator recorded only the alarms that were paged to nurse's phones and sent to the hallway marquee signs. The paged and recorded alarm types only represented a subset of the total possible alarm burden. The alarms recorded in the database are listed in Table 2-2. Emergin™ Orchestrator also recorded reminder alarms that were paged from the central station for alarms that remained unanswered for two minutes for all clinical alarms and after three minutes for all in-op alarms. All reminder alarm pages were sent every two minutes after the initial reminder alarm page.

2.4 Discovery of Specific Areas of Improvement

As the database was constructed, it was routinely examined for abnormalities and irregularities by comparing presumably similar quantities of recorded alarms. For example, if department A had an average of 15 “ECG Leads Off” alarms per patient per day and department B, with a similar patient population, had an average of only 5 “ECG Leads Off” alarms per patient per day, the “ECG Leads Off” alarm in department A would be highlighted as an area of potential improvement.

Another approach used to discover areas for improvement was a data intensive analysis. Alarms were grouped by department and by alarm type then plotted over time. The resulting plot had a simple linear regression trend line fitted in order to examine the slope of each data set. A positive slope indicated that an alarm type was becoming more frequent in a specific area while a negative slope indicated alarms were becoming less frequent. The slope values served as a quick index to highlight areas for investigation.

Personnel from clinical engineering then conducted observational studies in the various clinical departments for the alarm types identified as having a need for improvement. The purpose of the observations was to gather information and provide contextual information to the database information for the alarm in question. Information gathered included staff opinions regarding the general validity of the alarm, technological limitations, workflow observations, estimates of the frequency of non-actionable alarm occurrences. A problem statement was then created for each participating department based on the database analysis information gathered and the observational studies. This information was later presented to the working groups assembled from each department being studied.

2.5 Creation and Implementation of Countermeasures using Process Improvement

The problem statements created served as a starting point for the lean A3 process. The A3 process identified and implemented countermeasures to reduce the frequency of non-actionable alarms described in the problem statements.

The goal of the A3 was to determine if there was a feasible method of changing or creating standard work between the hospital departments in order to spread the most effective practices or technology to all departments using telemetry monitoring. The A3 format used was broken into two halves: the problem definition and the solution definition.

The problem definition contained seven sections: team members, problem statement, scope, background/current conditions, root causes, goals, and estimated project completion. The purpose of the problem definition was to work with a team of front line staff to refine the problem statement and to find possible root causes of the alarm in question.

The solution definition, or PDSA, contained four sections: countermeasures (Plan), implementation (Do), results/conclusion (Study), and follow-up actions (Act). The solution definition was created to outline potential countermeasures to the root cause found in the problem definition and to outline an implementation plan for the countermeasures. The implemented countermeasures were measured and revised.

2.6 Safety

As corrective actions were taken to reduce the frequency of clinically irrelevant non-actionable alarms, it was absolutely essential for the safety and efficacy of the alarm system to not be compromised. It was vital that the patient monitoring system provided same level of patient care. Safety was not quantitatively measured for this study. The changes made to the alarm monitoring system were qualitatively reviewed before, during and after implementation. Qualitative safety analysis was conducted by all parties involved, including nurses, clinicians, engineering and administration. Other studies have monitored safety by documenting the number of care escalations from critical care to intensive care, tracking the number of cardiopulmonary or respiratory arrests rescue events, and the number of opioid reversals [19]. The information required to track safety in this regard was not available at the time of the study.

3 Observations

The final database spanned a 212 day period from September 1st, 2012 to March 31st, 2013 and contained a combined total of 1,011,666 original and reminder alarms. In the medical/surgical environment, the average number of original alarms per patient per day (alarms/pt/day) was 19.0 (standard deviation (SD) = 39.4, median (M) = 5, total alarms (n) = 571,256). The average number of alarms, including reminder alarms, was 31.5 alarms/pt/day (SD = 50.4, M = 14, n = 947,730). The average number of unique beds monitored per day was 141.7 patient beds (SD = 12.9, M = 142, n = 30,039).

3.1 Overview of Database

The recorded subset of the total alarm burden placed on caregivers is detailed in Table 3-1 and Figure 3-1. The data displayed excludes "Department 3", which is a cardiac observation short stay unit and not standardized in the Emergin™ system that was used to create the database. The Table and Figure illustrate the mean total number of alarms per patient per day and the average sum of original alarms and reminder alarms per patient per day for the entire facility, separated by alarm type. As illustrated in Figure 3-1, the blue bars represent the original alarm condition as indicated by the central station while the red bars represent the total alarms received by the nurses on their phone. The total alarms received is the sum of the count of the original alarms and the two minute reminder alarms created by Emergin™. The most common recorded alarm type was SpO_2 low with an average of 5.5 alarms/pt/day and a standard deviation of 27.26. The large standard deviation suggests that a small number of patients contributed a large amount of alarms to the total count while the majority of the patients contributed a small number of SpO_2 alarms.

Table 3-1 Total Number of Alarms per Patient per Day by Type

	Original Alarms			Originals and Reminders		
Alarm Type	Mean/pt/day	SD	Total	Mean/pt/day	SD	Total
** SPO2T	5.50	27.26	165029	6.61	30.59	198554
* NON SUSTAIN VT	2.27	8.85	68172	3.26	13.01	97859
*** V-TACH	1.87	7.42	56004	2.05	8.17	61580
***TACHY	1.84	8.73	55144	2.08	10.09	62466
ECG LEADS OFF	1.13	1.50	34067	6.44	13.92	193505
*** DESAT	0.98	4.58	29519	1.17	5.46	35174
* PACER NOT PACE	0.98	6.65	29301	1.42	9.72	42618
* PAUSE	0.87	6.95	26109	1.18	9.73	35574
***BRADY	0.68	6.03	20524	0.74	6.58	22280
!!!REPLACE BATT. T	0.66	3.39	19910	0.70	3.48	20950
*** V-FIB/TACH	0.43	2.38	12844	0.48	2.81	14348
*** ASYSTOLE	0.38	2.28	11415	0.42	2.51	12579
* PACER NOT CAPT	0.30	3.93	9121	0.44	5.78	13234
* VENT RHYTHM	0.27	3.89	8155	0.47	7.48	14243
NO SIGNAL	0.24	0.57	7300	2.41	10.62	72272
BATTERY LOW T	0.16	0.38	4761	0.70	1.82	20974
All Others	0.02	0.91	13881	0.03	1.38	29520
Total	19.03	39.43	571256	31.55	50.44	947730

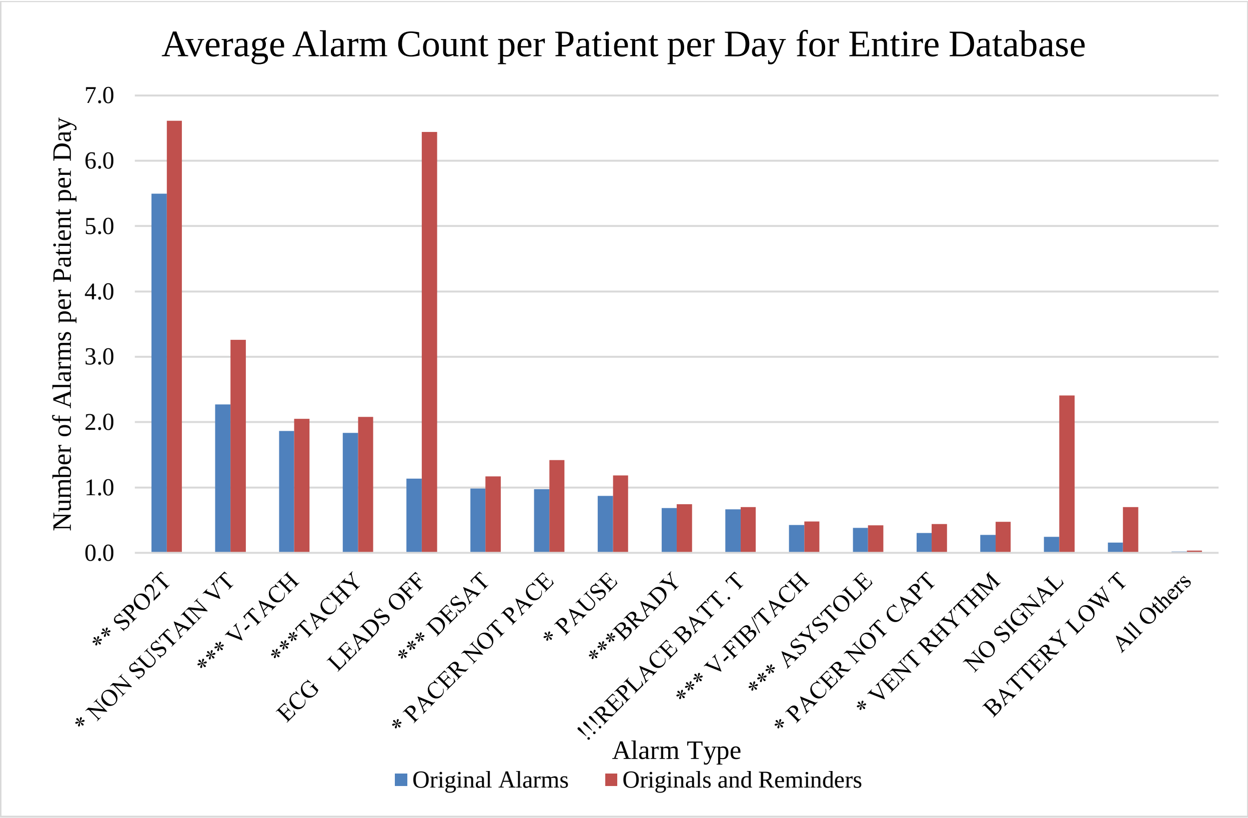

Figure 3-1 Average Alarm Count per Patient per Day for Entire Database

The mean of each individual alarm type throughout the entire sample was less than 7 alarms/pt/day. This value was calculated using all available data, including intervals of time where a patient experienced zero alarms. For example, if during any given day a patient does not generate a *** DESAT alarm, a zero was counted in the calculations for the mean number of oxygen desaturation alarms/pt/day. In order to examine the average alarm counts for only patients who had one or more alarm of any given type patients, all zero alarms/pt/day counts were eliminated. With the exception of ECG leads off, the results indicated that patients had either zero alarms or many alarms. This is especially obvious for SpO_2 alarms. The average alarm count/pt/day for all of the SpO_2 data was 5.5 alarms/pt/day, but the average daily SpO_2 alarm count calculated without including the patient days of monitoring that had zero SpO_2 alarms, i.e. excluding all zero SpO_2 alarms/pt/day from the mean calculation, was 47.1 alarms/pt/day. This can be partially attributed to the fact that not all patients receive SpO2 monitoring, but also illustrates a large portion of the alarm burden originating from a single source. Patients with known arrhythmias are expected to generate many alarms while the majority of the population are not expected to generate excessive alarms. For example, the population as a whole experiences 0.3 Vent Rhythm alarms/pt/day. This number takes into account all patient days of monitoring. Many patient days had a count of zero for the number of Vent Rhythm alarms. By excluding the zero counts, it was observed that patients that experience at least one Vent Rhythm alarm per day average 10.1 alarms/pt/day.

Table 3-2 Comparison Between Alarm Counts of Entire Sample and Sample Excluding Alarm Count of Zero

	Entire Sample - Alarm Type Count ≥ 0		Only Alarm Type Count ≥ 1		
Alarm Type	Mean/pt/day	SD	Mean/pt/day	SD	Total
** SPO2T	5.5	27.3	47.1	66.4	165029
* NON SUSTAIN VT	2.3	8.9	6.8	14.3	68172
*** V-TACH	1.9	7.4	5.6	12.0	56004
***TACHY	1.8	8.7	8.4	17.1	55144
ECG LEADS OFF	1.1	1.5	1.8	1.5	34067
*** DESAT	1.0	4.6	8.3	10.8	29519
* PACER NOT PACE	1.0	6.6	8.6	18.0	29301
* PAUSE	0.9	6.9	7.5	19.2	26109
***BRADY	0.7	6.0	9.5	20.5	20524
!!!REPLACE BATT. T	0.7	3.4	5.7	8.3	19910
*** V-FIB/TACH	0.4	2.4	3.0	5.7	12844
*** ASYSTOLE	0.4	2.3	3.5	6.1	11415
* PACER NOT CAPT	0.3	3.9	8.7	19.2	9121
* VENT RHYTHM	0.3	3.9	10.1	21.5	8155
NO SIGNAL	0.2	0.6	1.2	0.7	7300
BATTERY LOW T	0.2	0.4	1.0	0.2	4761
All Others	0.0	0.9	5.4	13.5	13881
Total	19.0	39.4	19.0	39.4	571256

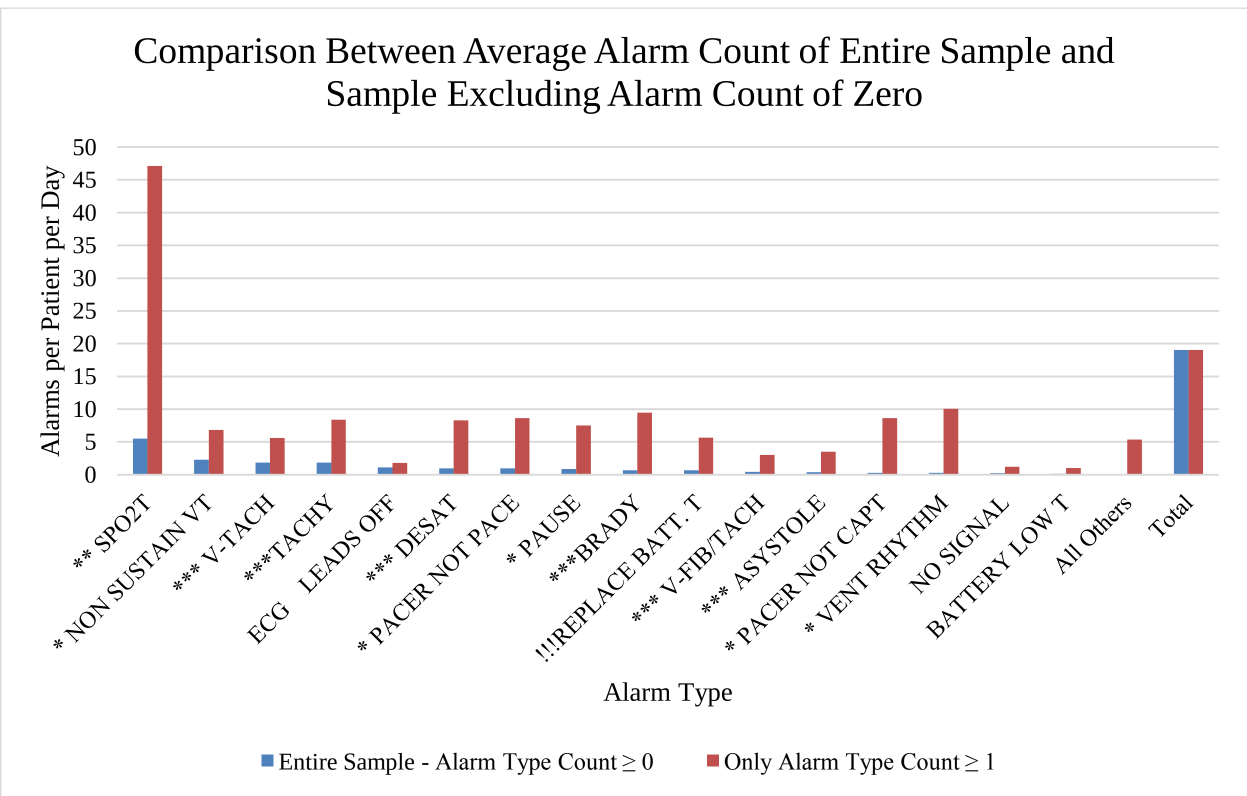

Figure 3-2 Comparison Between Average Alarm Count of Entire Sample and Sample Excluding Alarm Count of Zero

The majority of the data analysis was conducted on specific, individual departments. The breakdown of the alarm burden of only critical, red alarms by department is shown in Table 3-3 and Figure 3-3. The average number of red alarms/pt/day was 10.4. The mean alarm count/pt/day remained fairly consistent from department to department despite large differences in patient population.

Table 3-3 Average Count of Critical Red Alarms per Patient per Day by Department

	Original Critical Red Alarms				Originals and Reminder Critical Red Alarms			
Dept	Mean/pt/day	SD	Total	Median	Mean/pt/day	SD	Total	Median
Department 1	9.0	16.1	19066	3	9.7	17.3	20391	4
Department 2	8.3	15.7	17176	3	10.5	19.6	21601	3
Department 3	8.9	13.2	5011	4	10.0	16.0	5603	4
Department 4	8.7	16.8	9870	3	9.9	19.0	11231	3
Department 5	9.7	18.9	7805	4	14.9	26.1	12037	6
Department 6	9.5	17.1	14058	3	10.1	18.2	14957	4
Department 7	8.3	15.7	9189	3	9.9	18.8	10966	4
Department 8	8.8	14.0	8998	3	9.1	14.5	9278	3
Department 9	14.0	22.3	27906	6	14.0	22.3	27913	6
Department 10	11.4	15.7	18998	6	13.4	18.9	22310	7
Department 11	9.5	19.5	7437	3	9.6	19.8	7563	4
Department 12	11.8	23.2	14924	4	13.0	26.0	16352	4
Department 13	11.7	22.9	17567	3	12.1	23.9	18171	3
Department 14	11.3	19.5	12456	5	14.1	26.3	15657	6
Total	10.2	18.4	190461	4	11.5	20.8	214030	4

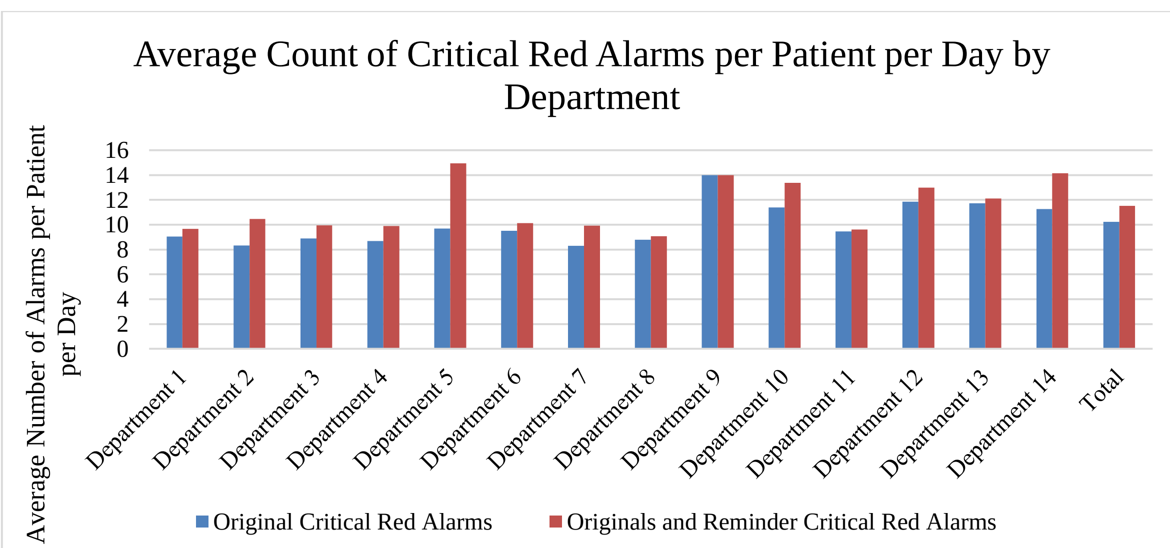

Figure 3-3 Average Count of Critical Red Alarms per Patient per Day by Department

The breakdown of the alarm burden of only high priority, yellow alarms by department is shown in Table 3-4 and Figure 3-4.

Table 3-4 Average Count of High Priority Yellow Alarms per Patient per Day by Department

	Original Yellow Alarms				Originals and Reminder Yellow Alarms			
	Mean/pt/day	SD	Total	Median	Mean/pt/day	SD	Total	Median
Department 1	13.2	29.6	48532	4	29.3	47.2	108049	14
Department 2	11.3	27.6	43895	3	22.3	38.9	86556	10
Department 3	41.0	59.2	36278	20	65.2	86.5	57801	34
Department 4	8.8	22.0	18390	3	17.9	32.3	37135	8
Department 5	14.0	30.5	19185	4	26.9	43.6	36866	10
Department 6	11.0	27.8	26299	3	23.8	43.7	57071	9
Department 7	6.3	15.5	11029	2	14.6	25.2	25655	7
Department 8	5.9	12.8	10333	2	15.6	24.5	27319	7
Department 9	8.5	18.7	19844	3	24.6	33.3	57499	13
Department 10	46.5	69.5	86083	18	58.7	76.2	108731	29
Department 11	12.0	29.6	14527	3	21.6	35.5	26143	10
Department 12	8.7	25.8	15509	2	22.6	38.0	40163	11
Department 13	10.8	27.5	25726	3	27.2	40.8	64943	12
Department 14	32.8	52.8	46454	14	44.6	60.6	63173	22.5
Grand Total	14.7	35.1	422084	3	27.7	46.9	797104	11

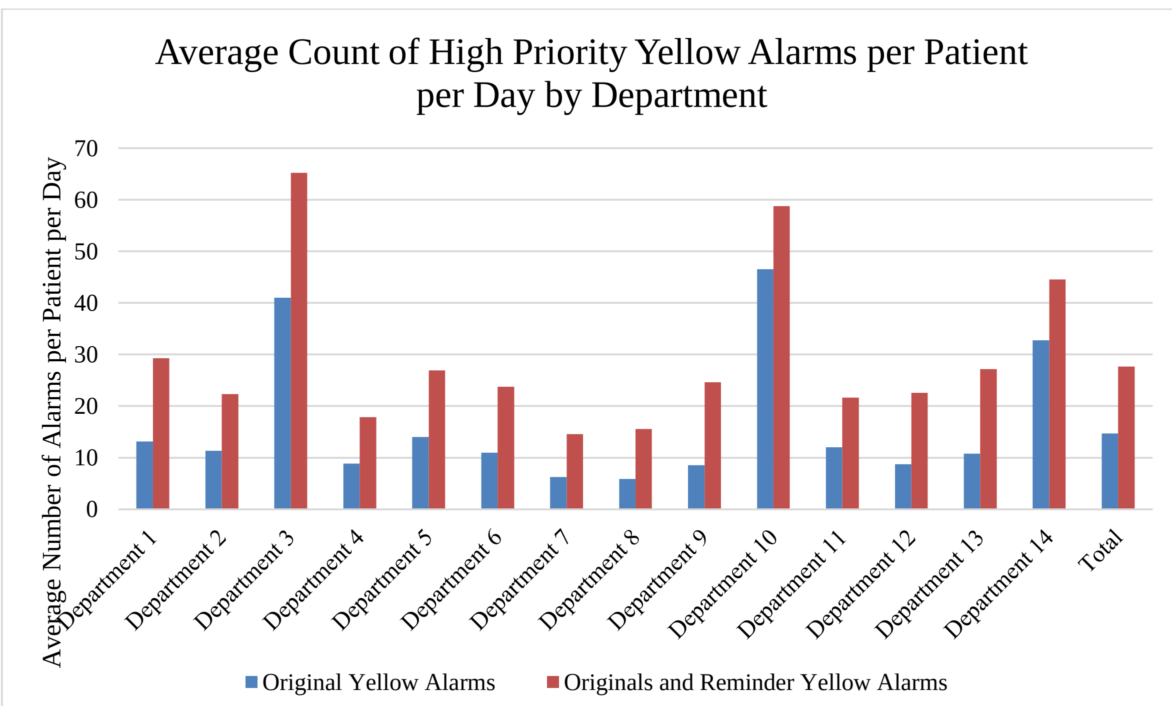

Figure 3-4 Average Count of High Priority Yellow Alarms per Patient per Day by Department

The ratio of original yellow alarms to their associated reminder alarms was much higher than the ratio of original critical red alarms to their associated reminders. This was due to the relative response time of red alarms compared to yellow alarms. As mentioned previously, “Department 3” was configured to page all alarms to the nurse’s phones and therefore all alarms were recorded in the database. “Department 10” heavily utilized SpO_2 monitoring which increased their total alarm count.

3.1.1 Observations in Department 1

The constructed database analyzed above contained a subset of the total alarms present in the system. The subset of alarms corresponded to the alarms paged to nurse phones, as illustrated in Table 2-2. One objective for determining the current state of the alarm system was to estimate the total alarm count for both recorded and not recorded alarm types. To approximate the total alarm population, a brief observation was conducted to create a rough estimate of the total count of alarms present. It was important to place the data recorded in the database in perspective with the entire alarm quantity. The observation was not intended to be a statistically significant study, but rather an informational exercise to help approximate the total alarm count. The observation was conducted in “Department 1”, a 24 bed adult cardiac medical unit. The observation was conducted by an observer at the central station manually counting the alarms as they were generated. The total duration of the observation was 9.5 hours. The observer was present over several days in sessions of less than two hours chosen randomly during the first and second shift only. The findings are shown in Table 3-5.

Table 3-5 Department 1 Observational Approximation of Alarm Frequency

Alarm Type	Total	Approximate Alarms per Patient per Day	Recorded in Database?
ECG leads OFF	60	7.6	Yes
Pair PVCs	49	6.2	No
Cannot Analyze ECG	43	5.4	No
Multi PVCs	39	4.9	No
IRR HR	22	2.8	No
RA Lead Off	20	2.5	No
HR Low	16	2.0	No
PVCS >10/MIN	14	1.8	No
Pacer not Capture	11	1.4	Yes
Non Sus. VT	10	1.3	Yes
No Signal	9	1.1	Yes
Tachy	8	1.0	Yes
HR High	6	0.8	No
V-Tach	5	0.6	Yes
All Others	26	3.3	
Total	338	42.7	

For comparison, the alarms recorded in the database for "Department 1" for the duration of the study are listed in Table 3-6.

Table 3-6 Department 1 Actual Alarm Frequency

Alarm Type	Mean/pt/day	SD	Total
* NON SUSTAIN VT	3.3	11.1	12762
* PACER NOT PACE	3.1	13.4	12044
*** V-TACH	2.0	7.7	7553
* PAUSE	1.9	13.6	7247
***TACHY	1.4	6.1	5394
ECG LEADS OFF	1.1	1.4	4345
* PACER NOT CAPT	0.9	7.6	3517
***BRADY	0.7	4.9	2630
* VENT RHYTHM	0.6	4.6	2114
** SPO2T	0.5	6.9	1962
*** ASYSTOLE	0.5	2.9	1951
*** V-FIB/TACH	0.3	2.4	1250
!!!REPLACE BATT. T	0.3	1.8	1175
NO SIGNAL	0.3	0.6	1012
All Others	0.1	1.6	2642
Total	17.6	36.1	67598

The observation gave evidence towards the magnitude of alarms not record in the database. Of 338 alarms observed, 209 alarms were not recorded in the database. The alarm types that were neither paged nor record accounted for 7 of the top 8 most common alarm types observed. The relative frequencies of each alarm were recorded and used for estimating the total alarm count. The observation suggested that as little as 32.1% of the total alarm count was recorded in database. The observation estimated an average of 42.7 alarms/pt/day while the database indicated only 17.6 alarms/pt/day, an 83.3% difference.

3.1.2 Total Alarm Count Estimation

To create an estimation of the total alarm count, "Department 3" was used as a comparison. In "Department 3", an admissions and observation unit, the central station was configured differently than it was in the other telemetry floors allowing every alarm type to be recorded into the database. The recorded alarm statistics are shown in Table 3-7. Alarms not usually recorded are annotated in the right column.

Table 3-7 Department 3 Alarm Frequency

Alarm Type	Mean/pt/day	SD	Total	Recorded in Database?
* PAIR PVCs	11.6	19.9	10645	No
* MULTIFORM PVCs	6.3	10.2	5778	No
* HR	6.2	16.4	5651	No
* NON SUSTAIN VT	4.0	8.9	3697	Yes
* IRREGULAR HR	3.4	11.8	3160	No
*** V-TACH	3.3	8.0	3013	Yes
* RUN PVCs	2.0	7.2	1804	No
* PVCs > 10/min	1.7	5.3	1534	No
* PACER NOT PACE	0.9	5.8	870	Yes
***TACHY	0.8	3.7	734	Yes
*** V-FIB/TACH	0.8	2.2	688	Yes
** SPO2T	0.6	6.3	521	Yes
* PAUSE	0.5	3.5	485	Yes
* R-ON-T PVC	0.5	1.6	440	No
* MISSED BEAT	0.4	1.8	374	No
All Others	0.1	1.4	1895	
Total	45.0	64.7	41289	

The data from “Department 3” indicated that, on average, 32 of 45 alarms per patient per day were not recorded in other departments, or 71.1% of the data was missing from the database. The data showed there were 8 alarm types in the top 15 that were not recorded in other departments. The red bar graphs in Figure 3-5 vividly illustrate the massive gap present in the database, and provide an idea regarding the data missing from other department’s alarm counts.

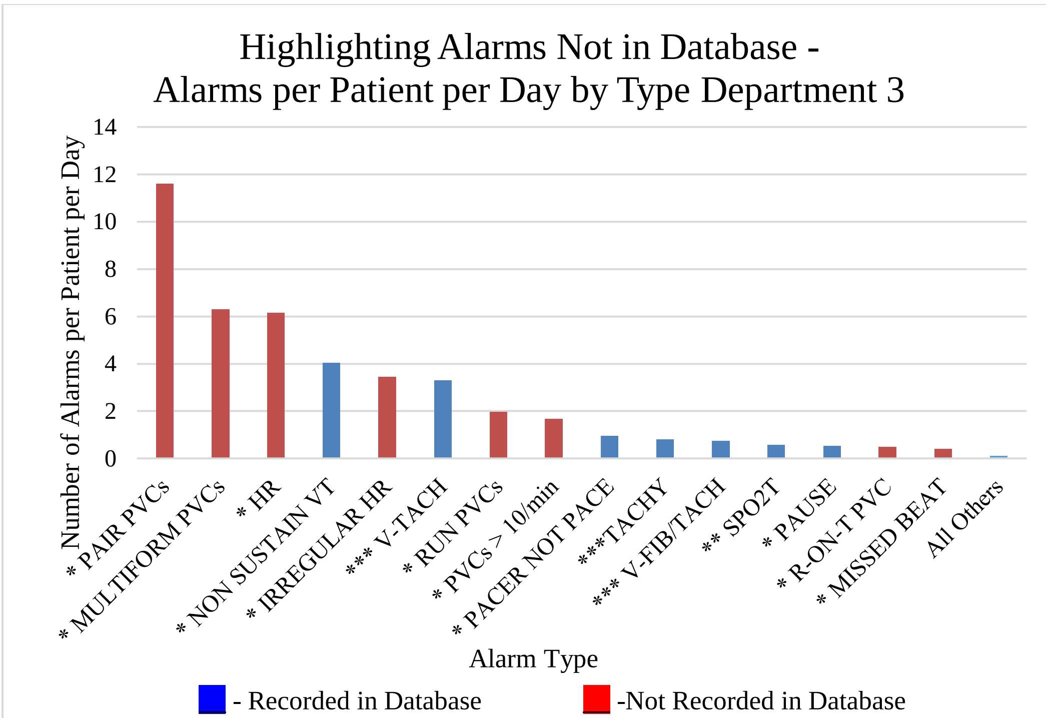

Figure 3-5 Department 3 Alarm Frequency by Alarm Type Highlighting Alarms Not in Database

The information from “Department 3” indicates that there was as little as 28.9% of the alarms recorded in the database for the other telemetry units. The mean alarm count was significantly higher than other departments at 45.0 alarms/pt/day. The alarms that were not recorded in the database were all yellow, high priority arrhythmias. Once again, the relative frequencies of each alarm type were recorded to estimate the total alarm count.

The objective of both the observations in “Department 1” and the gap analysis conducted on “Department 3” was to determine a finalized estimate for the frequency of each alarm type not recorded by the system. The frequency of each alarm type in the recorded subset of alarms and the estimated frequency of each of the alarms not recorded were assembled into Table 3-8 which shows the total alarm count per patient per day for each alarm type.

Table 3-8 Estimation of Alarm Frequencies Not Recorded in Database

			Original Alarms		Originals and Reminders	
			Mean/pt/day	SD	Mean/pt/day	SD
Recorded in Database	Critical Red Alarms	*** V-TACH	1.9	7.4	2.1	8.2
		***TACHY	1.8	8.7	2.1	10.1
		*** DESAT	1.0	4.6	1.2	5.5
		***BRADY	0.7	6.0	0.7	6.6
		*** V-FIB/TACH	0.4	2.4	0.5	2.8
		*** ASYSTOLE	0.4	2.3	0.4	2.5
	High Priority Yellow Alarms	** SPO2T	5.5	27.3	6.6	30.6
		* NON SUSTAIN VT	2.3	8.9	3.3	13.0
		* PACER NOT PACE	1.0	6.6	1.4	9.7
		* PAUSE	0.9	6.9	1.2	9.7
		* PACER NOT CAPT	0.3	3.9	0.4	5.8
		* VENT RHYTHM	0.3	3.9	0.5	7.5
	In-Op Alarms	ECG LEADS OFF	1.1	1.5	6.4	13.9
		!!!REPLACE BATT. T	0.7	3.4	0.7	3.5
		NO SIGNAL	0.2	0.6	2.4	10.6
		BATTERY LOW T	0.2	0.4	0.7	1.8
		All Others	0.0	0.9	0.0	1.4
Subtotal			19.0	39.4	31.5	50.4
Estimated; Not Recorded	High Priority Yellow Alarms	* PAIR PVCs	3.9		5.6	
		* MULTIFORM PVCs	3.2		4.3	
		* HR HIGH	3.1		4.6	
		* HR LOW	3.1		4.6	
		* IRREGULAR HR	1.7		3.7	
		* RUN PVCs	1.0		1.4	
		* PVCs > 10/min	0.8		1.1	
		* R-ON-T PVC	0.2		0.3	
Subtotal			17.0		25.5	
Total			36.0		57.0	

The estimations were calculated based on a conservative 50% estimate of the relative alarm frequency observed “Department 1” and “Department 3”. In other words, the relative frequencies of each recorded alarm compared to each estimated alarm were decreased by 50%. This decrease was meant to account for the predisposition of the observed cardiac environments to the arrhythmia alarms that were not recorded and therefore estimated. The estimate of the total fraction of alarms that the database contained was 19 alarms/pt/day compared to the estimated total alarm count of 36 alarms/pt/day. 36 alarms/pt/day served as the benchmark for reducing the total alarm count.

3.2 Description of Implemented Countermeasures and Results

A continuous process improvement cycle was utilized to routinely analyze the alarm database to discover potential areas of improvement. The following sections will discuss the identified and implemented countermeasures that attempted to reduce the amount of clinically irrelevant and non-actionable alarms.

3.2.1 Unlatching Yellow Alarms

Patient alarms broadcasted from the central station and throughout the monitoring system can be configured to behave in several ways: notifications, latched alarms, and unlatched alarms. Notifications are used for yellow, high priority, non-continuous physiological signals, like a Pair PVC arrhythmia. The alarm signal announces that the arrhythmia event has occurred and has a maximum duration of two minutes. Latched alarms are used for a continuous physiological signal and any red, critical alarm, like ‘V-Tach’. Latched alarms are continually announced until silenced by a nurse or physician. Unlatched alarms are only used for continuous, high priority yellow signals and can silence themselves i.e. the alarm signal will stop when the physiological condition creating the alarm stops.

After reviewing the initial alarm database that was representative of the current state, the quantity of “Reminder Alarms” created by latched yellow alarms, specifically low oxygen saturation, was found to be disproportionately large compared to the total number of other alarms generated. This prompted an investigation into the efficacy of the “SpO_2 Low” alarm type using the Lean A3 methodology. The Lean A3 found that nurses were required to do a substantial amount of unnecessary travel to the central station to silence false SpO_2 alarms generated by noise or clinically insignificant events. It was found that the unlatching of yellow alarms would eliminate the need to silence these false SpO_2 alarms and would reduce the amount of clinically irrelevant alarm related actions nurses would need to make.

The hypothesis was formed that un-latching SpO_2 alarms would lower the number of SpO_2 alarms and reduce the duration of SpO_2 alarms. On October 16, 2012, SpO_2 alarms were unlatched. Qualitative feedback from nurses and clinicians affirmed the change had a positive effect on nurses responding to SpO_2 alarms. The amount of SpO_2 alarms generated changed from 18.9 with 44.3 two minute reminders to 53.7 alarms with 6.9 two minute reminders. The number of SpO_2 alarms increased by 184%, the number of reminder alarm pages decreased by 84%. The decrease in reminder alarms is an indicator of the total duration of SpO_2 alarms.

The increase in alarms was a result of multiple short duration false or clinically irrelevant alarms occurring within the previous single alarm period. To estimate the decrease in the duration of SpO_2 alarms, the original alarm was assigned an average duration of 21 seconds and the reminder alarm duration was assigned 120 seconds. The original alarm duration of 21 seconds was determined using an evidence based study that showed that 70% of SpO_2 alarms have a duration of less than 15 seconds, determined by applying a 15 second alarm delay. This meant that 70% of the 53.7 SpO_2 alarms post un-latching, or 37.6 alarms, have a duration of less than 15 seconds [20]. The 21 second alarm duration was believed to be an over estimate to account for the duration of true alarms, but the actual duration was not measured in this study.

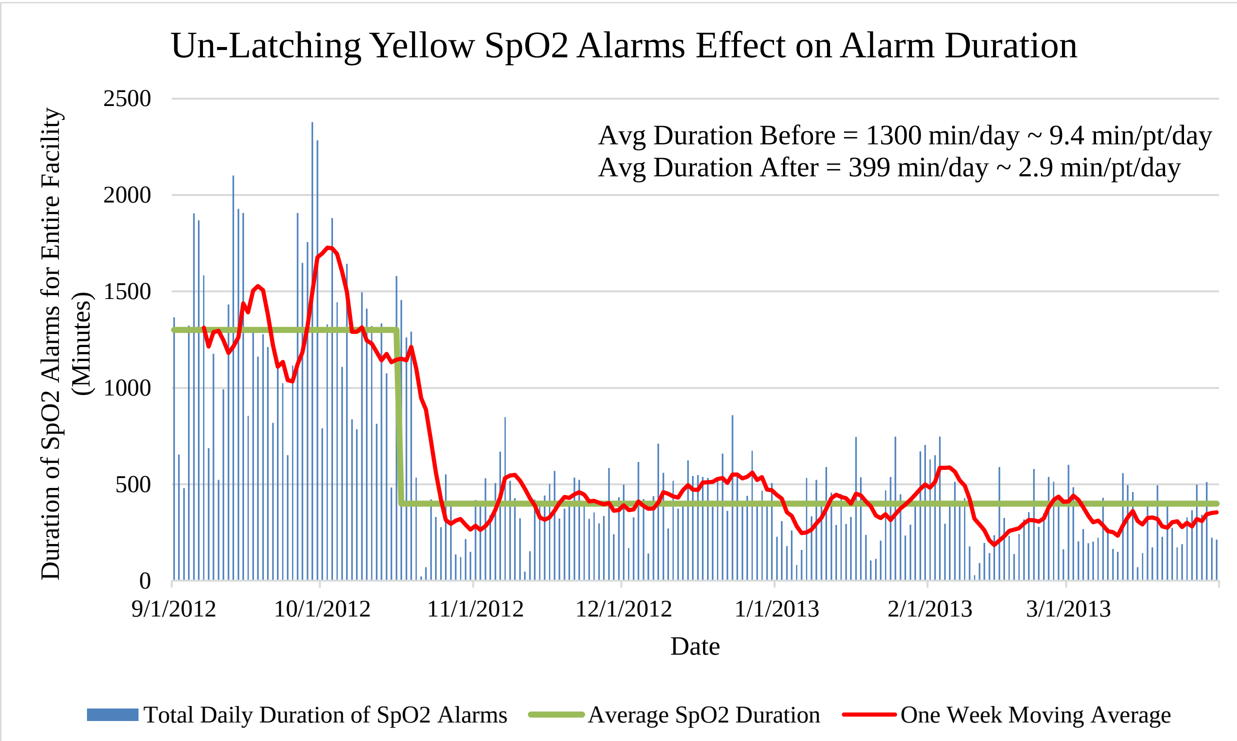

Figure 3-6 Un-Latching Yellow SpO_2 Alarms Effect on Alarm Duration

The average duration of SpO_2 alarms dropped approximately 68% from 9.4 minutes/pt/day to 2.9 minutes/pt/day. The consensus in the hospital was that SpO_2 alarms that resolved themselves within a matter of seconds had no bearing on the patient's clinical condition. The reduction of the total duration of SpO_2 alarms decreased the background noise in the units. The hypothesis that the quantity of SpO_2 alarms would decrease was shown to be false. Original alarms increased 184% and reminders decreased 84%. The hypothesis that the duration of SpO_2 alarms would decrease was shown to be true with a -68% reduction.

3.2.2 Telemetry Nursing Re-Education for Phone Assignment, Pacemaker Settings and Atrial Fibrillation - Department 11

After reviewing the database in an effort to discover areas for improvement in the alarm system, several common, reoccurring errors where identified. “Department 11” was chosen as a site to implement a series of small countermeasures to these common problems. The purpose was to reinforce standard practice already in place to counter the observed common problems.

The prevalence of “Pacer Not Paced” and “Pacer Not Captured” alarms was recorded throughout the system as a common alarm. It was believed that the relative rates of these two alarms compared to other alarms was higher than the actual clinical presence of the condition. The telemetry system was configured to default to the patient having a pacemaker, meaning the attending nurse had to disable the pacemaker setting for every patient who did not actually have a pacemaker. Failure to disable the pacemaker setting when appropriate would result in many false, clinically irrelevant alarms. The consequences for failing to disable this setting were viewed as favorable compared to the opposite, where failure to enable the setting when appropriate could negatively affect the safety of the patient who has a pacemaker but the telemetry system is not configured to account for the pacemaker spike in the arrhythmia algorithms. The nurses in “Department 11” were retrained in the standard practice of disabling the defaulted on pacemaker setting for patients without a pacemaker.

The prevalence of the “Irregular HR” alarm was suspected to be high. The “Irregular HR” alarm was recorded as a frequent alarm in “Department 3” and observed as a frequent alarm in “Department 1”. The “Irregular HR” alarm was announced when there was an irregular R – R interval [21]. This was common during periods of atrial fibrillation. Patients with known, clinically insignificant atrial fibrillation would constantly create false “Irregular HR” alarms; standard practice for this case was to disable the “Irregular HR” alarm to prevent nuisance alarms. The nurses in “Department 11” were retrained in the standard practice of disabling the “Irregular HR” alarm for patients with known, clinically insignificant atrial fibrillation.

The secondary alarm notification system sent text pages to each nurse cell phone for the alarm types recorded in Table 2-2. Each nurse was sent an alarm text for only the alarms originating from patients that the nurse was responsible for. This functionality filtered the alarms from the central station that reached each nurse. The cell phones replaced the need for the nurse to utilize other distribution methods to determine if the alarm required their attention. In order to encourage team work and increase accountability, the secondary alarm notification system was reconfigured to page all alarms to every nurse. Additionally, measures were put in place to formally ensure every nurse had a phone properly assigned and configured in the telemetry system.

These three countermeasures were implemented during the last week of January. The effects of the re-education and phone re-assignment were mixed. The “Pacer Not Paced” and “Pacer Not Captured” alarms had no significant change in frequency. The “Irregular HR” alarms were not recorded in the database, therefore there was no method of monitoring the expected reduction. The effects of the phone reassignment were unknown before implementation. There were, however two observed effects of the implementation: a decrease in the number of battery related in-ops and a downward trend in the frequency of all reminder alarms. Battery related in-ops were reduced from a mean of 9.8/pt/day (SD = 5.3) to 7.0/pt/day (SD = 4.7), illustrated in Figure 3-7. The number of reminder alarms trended downward from January 1st to March 31st and is illustrated in Figure 3-8.

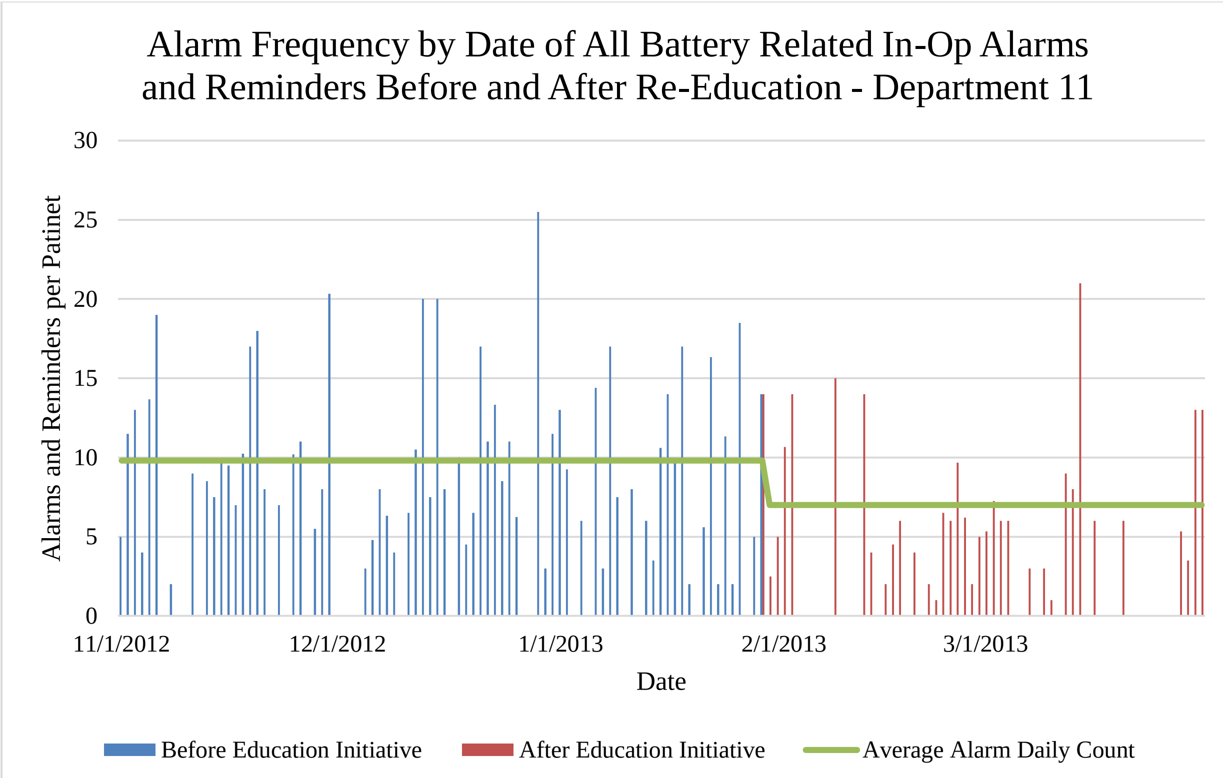

Figure 3-7 Alarm Frequency by Date of All Battery Related In-Op Alarms and Reminders Before and After Re-Education - Department 11

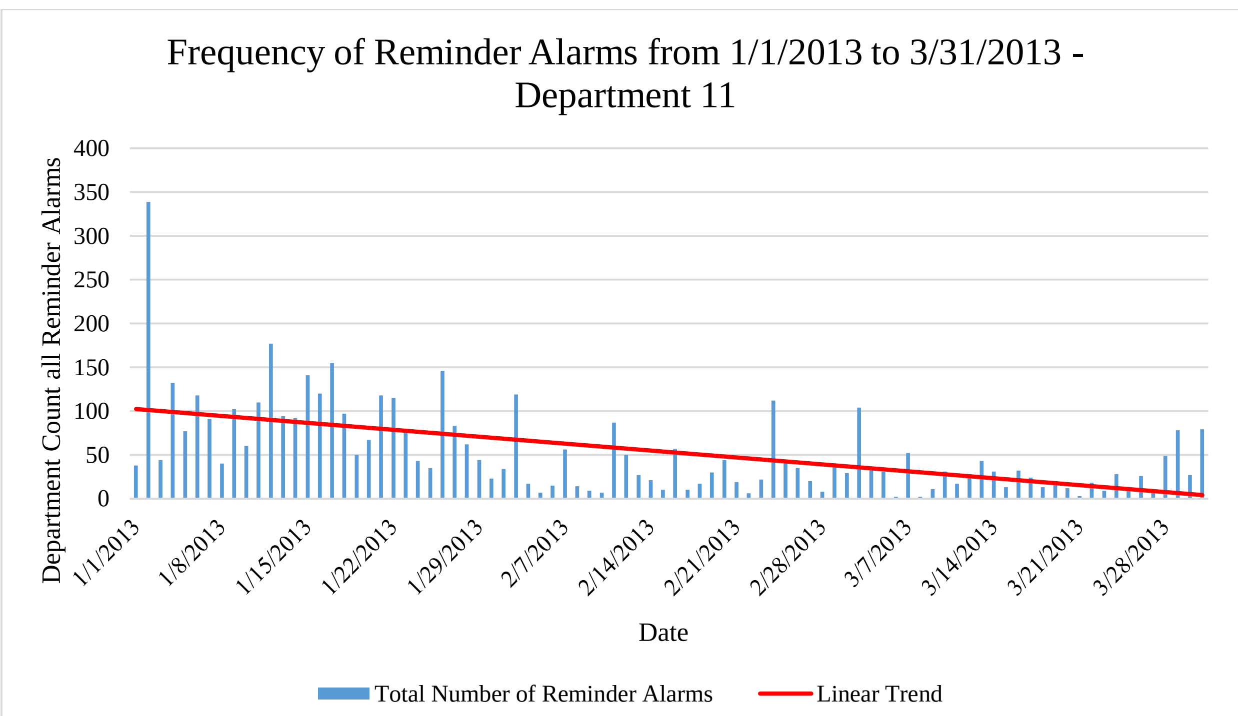

Figure 3-8 Frequency of Reminder Alarms from 1/1/2013 to 3/31/2013 - Department 11

3.2.3 Alarm Suspension from Telemetry Pack - Department 1

During the database review, it was observed that the number of "ECG Leads Off" alarms in "Department 1" was higher than other departments. A formal Lean A3 process was used to determine the approximate root causes of the excessive ECG leads off as well as potential countermeasures to combat the root causes. One potential cause that was identified as contributing to high frequencies of leads off conditions was the inconvenience of silencing the central station and placing the monitor on standby while in the patient's room. A spaghetti diagram, which maps the walking done by staff, illustrated the amount of time nurses spent travelling between patient rooms and the central station to appropriately handle leads off alarms.

To combat this problem, a functional button inherent to the telemetry packs was enabled and configured to suspend the monitor for three minutes. This would allow nurses to suspend the monitor remotely from the patient's room before undertaking an action that would knowingly create an ECG leads off condition, e.g. remotely suspending monitoring before replacing ECG electrodes thus eliminating the need to leave the patient to travel to the central station to suspend monitoring. This functionality would also allow a caretaker to suspend monitoring from the telemetry pack while an alarm was being resolved, potentially reducing the time between the alarm being announced and silenced and therefore reducing the number of subsequent reminder alarms. The hypothesis was that enabling the functionality that allowed for remote suspension of monitoring would decrease ECG leads off alarms by eliminating unnecessary walking needed to prevent alarms induced by standard patient care and would reduce all reminders by creating a way to silence alarms remotely.

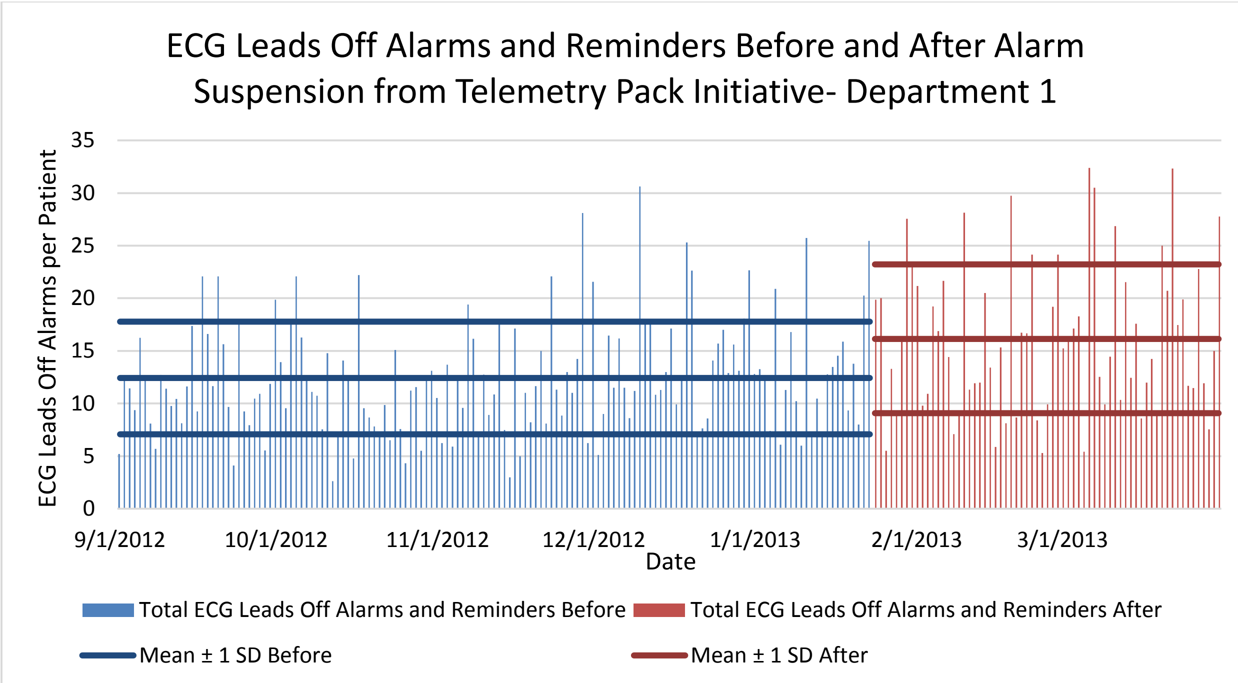

Figure 3-9 ECG Leads Off Alarms and Reminders Before and After Alarm Suspension from Telemetry Pack Initiative- Department 1

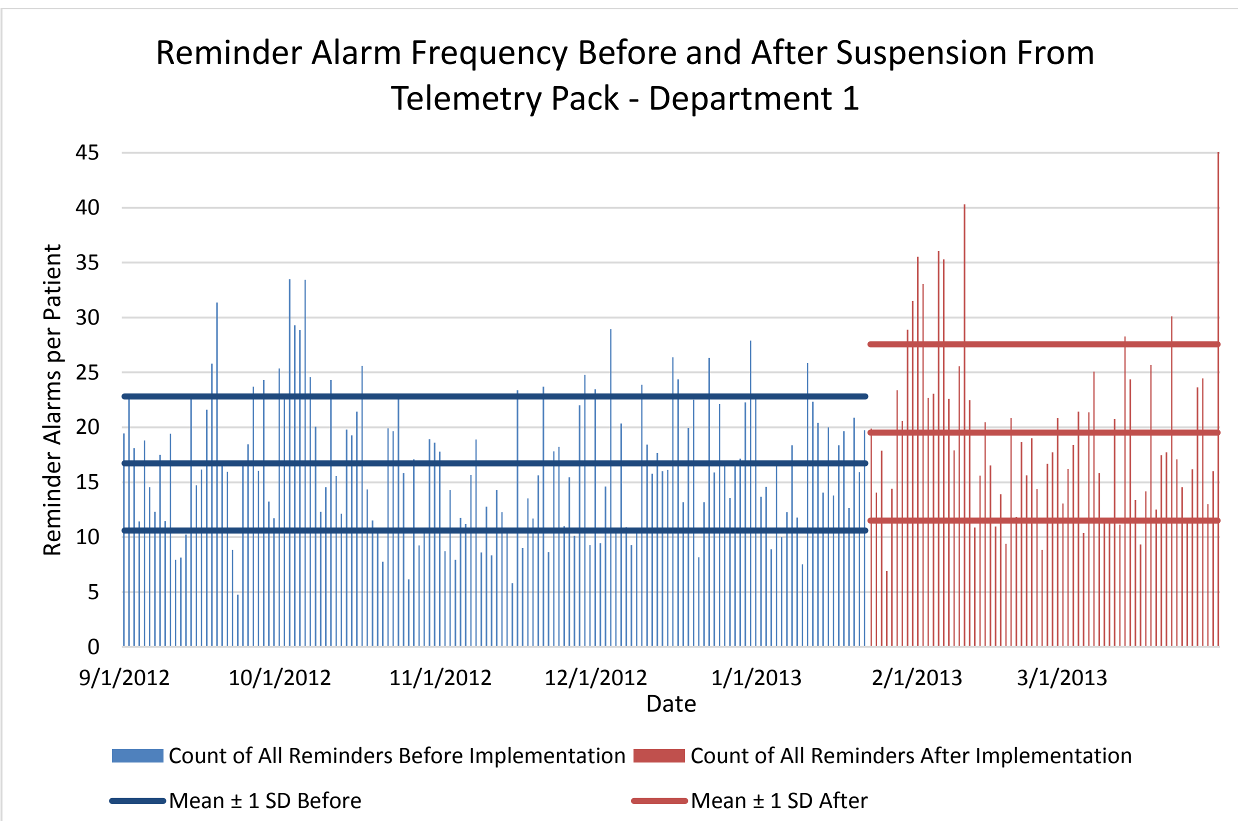

Figure 3-10 Reminder Alarm Frequency Before and After Suspension From Telemetry Pack - Department 1

The functionality was implemented and trained on January 24th. There was no reduction in ECG Leads Off alarms or reminder alarms after implementing the countermeasure to suspend monitoring from the telemetry pack. The results of the countermeasures are shown in Figures 3-9 and 3-10. There was a marginal increase observed in both the alarm categories where a reduction was expected. The failure to demonstrate a reduction in alarm frequencies was potentially due to low utilization rates of the new functionality. Additional training and increased familiarity with the technology may reverse the findings.

3.2.4 Daily Electrode Change - Neurological ICU

One Lean A3 was conducted outside of the telemetry departments that were examined throughout the rest of the study. The A3 was conducted in a neurological ICU in an effort to combat “ECG Leads Off” alarms. This area was thought to be the most difficult area for solutions to leads off alarms due to the patient population where it was common to have non-lucid patients regularly pulled their own leads off. Previous studies have found success in reducing both leads off and all other alarms through conducting a daily electrode change [17]. The electrodes in use were rated for 72 hours. During the countermeasure, the electrodes were changed every 24 hours to measure any effect on alarm frequencies. The hypothesis was that changing electrodes daily would reduce the number of “ECG Leads Off” alarms.

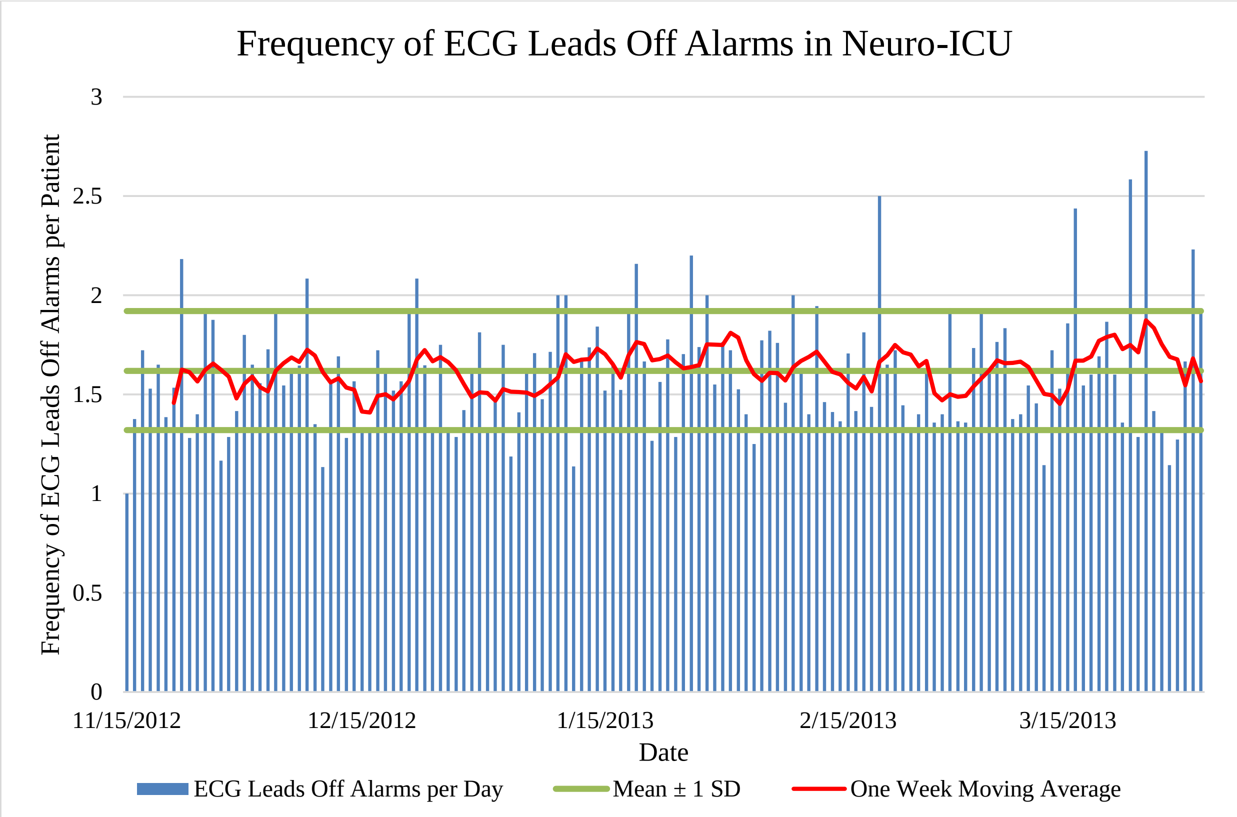

Figure 3-11 Frequency of ECG Leads Off Alarms in Neuro-ICU

The daily electrode change was implemented on January 18th, had no effect on the rate of leads off alarms and was abandoned after a week. The "ECG Leads Off" alarms for the neuro-ICU are shown in Figure 3-11. After the failure, it was proposed that the countermeasure was not addressing the appropriate point of failure in the system. The common method of leads off alarms in the neuro-ICU involved the lead set pulling off of the electrode, not the electrode pulling off of the skin. This was thought to be due to the patient population where it was common to have patients who were not lucid regularly pull their own leads off. This was not documented through any formal process but was the general observation of the nurses conducting daily electrode change.

3.3 Description of Planned Countermeasures and Expected Results

The research project team planned four countermeasures that were not implemented due to time restraints. The countermeasures were approved and the expected results were predicted using both the database of recorded alarms and the estimated total alarm frequencies derived from observations and the department configured to record all alarm types as explained in section 3.1.2.

3.3.1 New Default Adult Cardiac Telemetry Parameters

The majority of patients were monitored using the default cardiac alarm settings. These settings are shown in Table 7-1 of the appendix. There was a number of alarms that seemed to add no value to the system and almost entirely added to the noise by being a default alarm that was clinically irrelevant. For example, a high heart rate alarm of 121 bpm was not a piece of information that added anything to the patients care. Default alarm changes to eliminate clinically irrelevant alarms have been shown to significantly decrease the total alarm count. An example of a reduction in alarms based on assessing alarms to be clinically irrelevant would be changing the high heart rate alarm limit from 120 to 130. In one study, analysis of alarm history concluded this would result in a 50% decrease in the heart rate alarm load [5].

The default cardiac parameters of the telemetry system were reviewed with the intention of eliminating all alarms that did not possess clinical relevance with respect to the patient's care. The default alarms were reviewed by a diverse team of clinicians and healthcare professionals including members of cardiology, electrophysiology, surgery, nursing, hospitalists, and medicine. The current settings were revised with ten potential changes proposed. The changes are in the process of being vetted and approved. Table 3-9 represents a preliminary draft of the proposed changes to the telemetry default parameters. Alarms not listed did not have a proposed change.

Table 3-9 Potential Alterations to the Current Default Cardiac Telemetry Parameters

Item	Current Settings	Suggestion for New Setting	Comments/Notes
HR High Limit	> 120 b/min	>140 bpm	SVT is better tolerated and this would eliminate unnecessary alarms
HR Low Limit	< 50 b/min	< 40 bpm	Alarms at night a concern
Run PVCs	Enabled > 2 PVCs	> 3 PVCs	Same as Definition of NSVT
Vent Rhythm	Vent Rhythm Limit: > 14 PVCs	eliminate	no clinical relevance
Pair PVCs	Enabled	eliminate	
Vent Bigeminy	Enabled	eliminate	no clinical relevance
Vent Trigeminy	Enabled	eliminate	no clinical relevance
Pause >	Enabled 2.0 seconds	3 seconds (2.5 seconds is maximum the system allows)	2 second pause has no clinical significance
Pacer Not Capture	Enabled	Upgrade to Critical Red Alarm	
Pacer Not Pace	Enabled	Upgrade to Critical Red Alarm	

Effort was placed into predicting the effects to the proposed changes. Data was only available in the comprehensive alarm database for “Vent Rhythm”, “Pacer Not Captured” and “Pacer Not Paced”. Estimates of reductions for the remaining parameter changes were extrapolated from the data recorded in “Department 3”, shown in section 3.1.2. The new default parameters for high and low heart rate alarms would have eliminated a total of 8079 alarms in “Department 3” over the course of the study, equaling an 89.5% reduction as shown in Table 3-10.

Table 3-10 Heart Rate Alarms Potentially Eliminated by Default Parameter Changes in Department 3

Alarms Potentially Eliminated	Eliminated Alarm Count	Total Alarm Count	Reduction
Limit Change of 50 bpm to 40 bpm	4165	4465	93.3%
Limit Change of 120 bpm to 140 bpm	3914	5067	77.2%
Total High Priority Yellow HR Alarms	8079	9022	89.5%
Total of all Red and Yellow HR Alarms	8079	9532	84.8%

Figure 3-12 illustrates the frequency of each heart rate recorded at the time of the alarm. Heart rates displayed in red will be eliminated by the change in the default profile. These estimates where recorded in “Department 3” and were measured in alarms/pt/day. The observed alarm frequencies were used to estimate the expected total reduction in heart rate alarms.

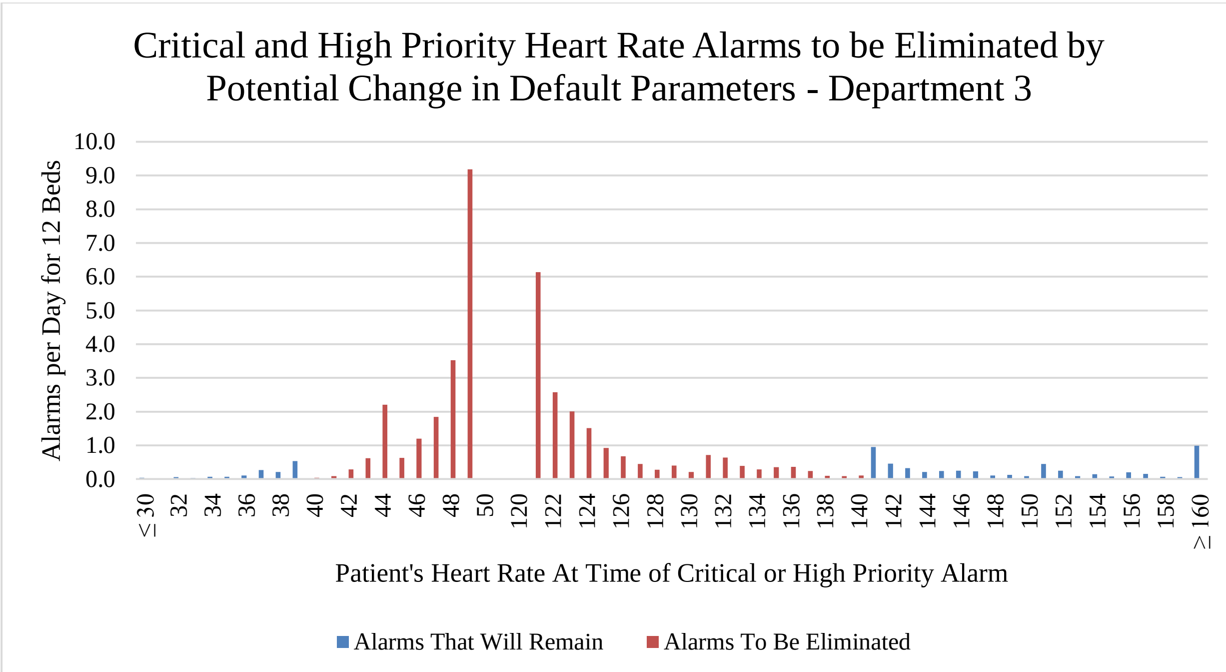

Figure 3-12 Critical and High Priority Heart Rate Alarms to be Eliminated by Potential Change in Default Parameters - Department 3

The estimations for the reductions in alarms from changing the default parameters to the proposed new parameters would create the reductions estimated in Table 3-11.

Table 3-11 Alarms/pt/day Potentially Eliminated by Default Parameter Changes

Alarm Type	Potential Reduction	Potential Alarms/pt/day Eliminated	Potential Alarms and Reminder Alarms/pt/day Eliminated
HR High Limit	93%	3.3	4.2
HR Low Limit	77%	2.4	3.5
Vent Rhythm	100%	0.3	0.5
Pair PVCs	100%	3.9	5.6
Run PVCs	Unknown	-	-
Vent Bigeminy	Insignificant	-	-
Vent Trigeminy	Insignificant	-	-
Pause	Unknown	-	-
Total		12.8	18.1

The estimated reductions for heart rate alarms were explained above. The estimated reduction for “Vent Rhythm” and “Pair PVCs” were taken directly from the estimations of the total alarm burden per patient per day shown in Table 3-8. The estimated reduction from changing the parameter threshold that was used for the “Run PVCs” and “Pause” alarms were not able to be estimated. Both alarms were recorded in the database but neither alarm recorded the condition of the patient at the time of the alarm; the alarm conditions were recorded as Boolean values. Therefore, there is no method of using the database to estimate the effect of changing the “Run PVCs” parameter from 2 PVCs to 3 PVCs and changing the “Pause” parameter from 2.0 seconds to 2.5 seconds. The total estimated reduction for the default parameter change was 12.8 alarms/pt/day and 18.1 total alarms/pt/day, including reminders/pt/day.

3.3.2 Alternate Site Monitoring Decision Algorithm for Pulse Oximetry - Department 10

Database analysis revealed that the number of SpO_2 alarms in “Department 10” were very high compared to similar departments. Pulse oximetry was widely used in “Department 10” due to the patient population of adult surgical orthopedic patients. This includes patients who were ambulating using a walker, patients actively gripping a trapeze bar for assisting with movement, patients who were known to have poor profusion and patients who were non-complacent and purposefully removing their sensor. An investigation into the utilization of SpO_2 revealed the only modality used was a boot sensor placed on a digit.

To combat the described problems, multiple modalities of SpO_2 monitoring were planned to be incorporated into the standard practice. An algorithm for determining which modality was appropriate was designed by the clinical staff on the unit. The primary modality remained the boot sensor placed on a finger. Additional sensor types and locations were an ear clip sensor, a disposable finger sensor with adhesive, a forehead sensor and a multisite reusable sensor with a disposable band.

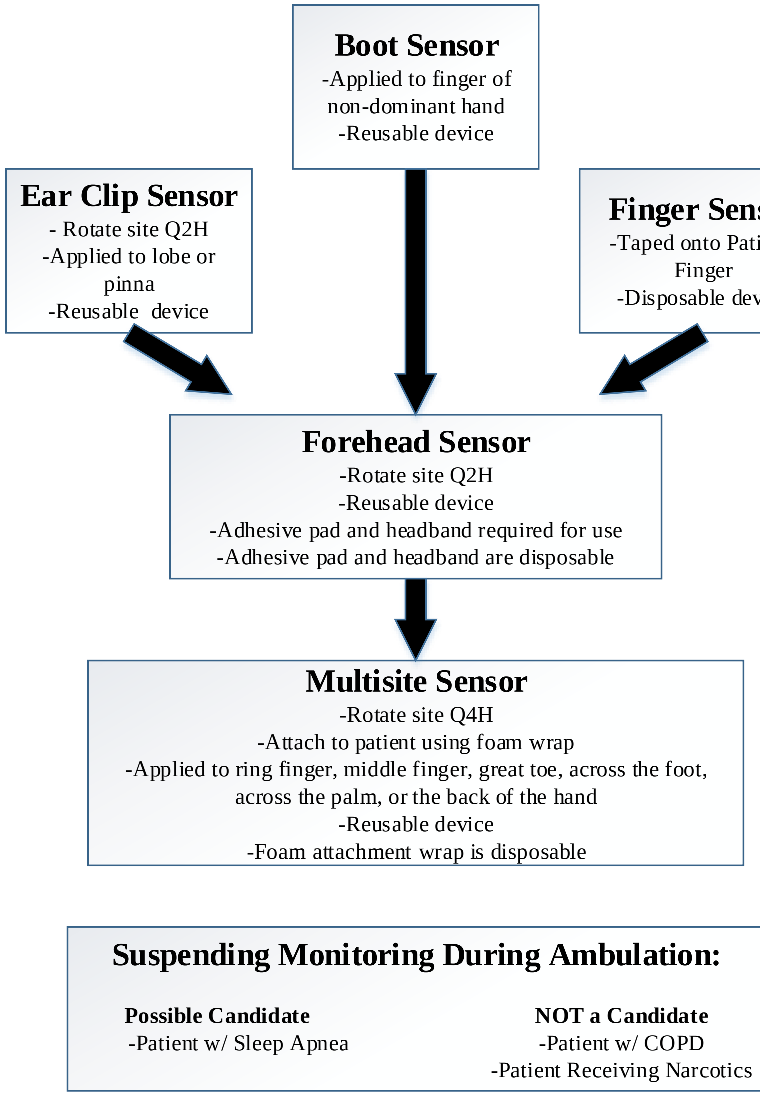

Figure 3-13 SpO_2 Alternate Site Selection Algorithm (Received in communication)

The purpose of the pulse oximetry alternate site selection algorithm was to provide nurses with the technology necessary for providing the best care possible. The additional SpO_2 options were designed to ensure that the monitoring technology is properly utilized.

3.3.3 Telemetry Order Set

Medical and surgical floors generally take one of two approaches to monitoring patients. Some hospitals choose a comprehensive, continuous monitoring approach where every patient is monitored for the duration of their stay in the hospital. The studied hospital takes a selective patient monitoring approach were only patients indicated for use of telemetry are monitored.

A study at the hospital found that patients who are not indicated for use of telemetry monitoring did not receive any clinical benefit or enhancement to patient care. The study concluded that during 35% of the days of telemetry monitoring, the use of telemetry monitoring was not supported by an accepted set of clinical indications. Arrhythmia occurrence during the non-indicated days of monitoring was 3.1 arrhythmias per 100 non-indicated days of monitoring. The detected arrhythmias were found to be clinically insignificant [22].

The alarm team concluded that reducing telemetry utilization to only patients indicated for use was a safe way to decrease the number of total alarms. Patients who were non-indicated for use of telemetry would theoretically produce only clinically irrelevant nuisance alarms and in-op alarms. Eliminating all non-indicated initiation and ensuring timely discontinuation of telemetry monitoring would have a significant impact on the total alarm burden.

The preliminary set of indications for initiating cardiac monitoring and criteria for discontinuation are provided in Appendix Table 7-4. The indications are a modified version of the American Heart Association guidelines for initiation and discontinuation of cardiac telemetry. The new order set for telemetry using the clinical guidelines is planned to be implemented as part of Computerized Physician Order Entry (CPOE). Once implemented, the order set will reduce the number of patients monitored by telemetry and will therefore reduce the number of clinically irrelevant and in-op alarms.

3.3.4 Pulse Oximetry (SpO_2) Order Set

The ordering practice for pulse oximetry was not standardized. Policy and practice at the hospital required that SpO_2 monitoring was always used with ECG monitoring, never only SpO_2 monitoring. There were clinical situations where only monitoring SpO_2 without ECG would have been acceptable to sufficiently maintain patient safety. Caregivers used clinical judgment to determine that there were situations were only SpO_2 monitoring would have been sufficient for patient care. Examples of possible situations that a caregiver could make a clinical judgment where only SpO_2 would be sufficient are apnea monitoring, CPOD monitoring or opioid administration monitoring.

In situations where only SpO_2 monitoring was sufficient, alarms resulting from ECG monitoring would be clinically irrelevant. To reduce the amount of ECG alarms resulting from situations where only SpO_2 is sufficient, the ordering process for SpO_2 was planned to be standardized and un-coupled from ECG monitoring. The ordering process would allow SpO_2 monitoring to be ordered independently of ECG monitoring. The goal was to provide the right amount of care at the right time. The SpO_2 monitoring order set was to be implemented using CPOE, similar to the planned ECG order set. The indications were not finalized or implemented.

4 Discussion

Iterative process improvement combined with database analysis for providing the case for change and results of countermeasures was a successful methodology for conducting an alarm fatigue reduction initiative. Presenting alarm data was a key motivator for inspiring change. A consensus existed that alarm fatigue was a problem but not until the problem was quantified and presented numerically was there a method for focusing on specific changes to address the excessive alarms.

The countermeasures planned and implemented did not focus on one single aspect of the alarm system. The countermeasures address problems with the technology, clinical use, people, workflow, process, and policy. There was no silver bullet solution to prevent alarm fatigue. The work completed here did show, however, that there was an iterative process that could be undertaken to identify specific, manageable actions to minimize alarming. Currently, the results of this thesis show preliminary accomplishments where establishing the process for alarm reduction and creating the momentum for change were the key successes.

4.1 Limitations of the Study

One limitation of this study was the incomplete database used for the alarm analysis. The alarms captured within the database painted a vivid picture of the alarms recorded and was used for finding problems and measuring the effects of solutions. Data was systematically estimated and extrapolated for the alarm types not recorded in the database. Several reported alarm reductions for expected results of the planned countermeasures were, in part, based off those estimates. The validity of the study would improve if actual data was used to show the precise effect of each implemented countermeasure. The database analysis process for discovering new opportunities for improvement and potential countermeasures relies on recorded data. Without recorded data for every alarm, the iterative improvement process is “blind” to creating new cases for change and measuring the effects implemented countermeasures.

The second limitation of this study was the absence of quantified measurements of safety metrics for the implemented alarm countermeasures. Other studies have tracked metrics like escalations in care from acute care to intensive care, the frequency of rescue events, and frequency of opioid reversals [19]. There is an opportunity for improvement of the study by quantifying safety. The safety of each countermeasure was discussed with clinical staff before implementation to ensure the safety of the patients involved. Providing safety data from either tracked metrics or latent variable analysis to illustrate the safety of the countermeasures would improve the study.

A third limitation of the study was found through the observations conducted to provide additional information about alarm types not recorded in the database and provide information about metrics not captured by the database like response time or method used for alarm resolution. The simple presence of an observer corrupted the results of the observation. A nurse was even heard saying “make sure you respond to your alarms because they are here watching today.” This is called the Hawthorne effect. The Hawthorne effect is a reaction to an observer where the worker improves or modifies their response patterns because they know they are being measured [23]. This alternation of the response to alarms affects the data and does not represent reality. There is opportunity for improvement of the study by finding a way to measure the desired metrics automatically.

4.2 Alarm versus Event

The current policy in place in the telemetry departments states that every alarm must be responded to by a nurse in a timely manner. This policy required nurses to respond to approximately 36.0 alarms/pt/day. For example, if a nurse had six patients assigned to them, they would have approximately 72 actions they would need to make in a single shift simply to comply with the alarm policy stating they need to respond to every alarm. In reality nurses do not need to respond to every single alarm and instead rely on their clinical judgment to determine which alarms are clinically relevant and clinically irrelevant. Certain alarms are used to determine the patient's condition and trend their health. For example a nurse may observe the number of yellow, high priority arrhythmias without taking immediate action but rather using the information as an indicator.

The alarms that truly require immediate action and the alarms that are providing useful and relevant clinical information are distributed using the same methods. Formally differentiating these two signals and distributing them separately would help increase the signal to noise ratio of the alarm system.

Definitions were created to differentiate the two categories. An alarm was defined as a signal which requires immediate response and action. An event was defined as an important situation that can be reviewed promptly but retrospectively. Labeling certain traditional alarms as events and removing them from distribution through the same channels would reduce the number of clinically irrelevant alarms reaching the nurses and decrease the number of required alarm response actions needed throughout the day.

4.3 Reproducibility of results

A challenge that the project will face moving forward as the successful countermeasures are spread to other departments throughout the hospital and potentially other hospitals is the reproducibility of the results. Hospital departments by nature vary slightly in culture and practice. Different patient populations will affect the reproducibility of the results of the countermeasures. Technology that is not standardized can also affect the reproducibility of the countermeasures. For example, the SpO_2 monitoring was configured to default to "spot check" or periodic measurements in one area and "continuous" in another. This will affect the departments who utilize the SpO_2 "spot check" functionality when they attempt to implement the independent SpO_2 monitoring countermeasure as they will not be able to get the SpO_2 to function without ECG in this mode. The daily electrode change countermeasure in the Neuro-ICU is an example of a successful countermeasure from a different hospital being ineffective in a different environment. The iterative process improvement cycle should be used for every department. Although not all departments are the same, after using process improvement to identify a specific problem, previous countermeasures and results of the successful countermeasures are useful, providing a solution without the need to recomplete the improvement process.

4.4 Future Work

This thesis completed some of the more difficult tasks needed to begin a project of this scope, such as recruiting support and completing the initial database and countermeasures. The thesis did leave work undone. There is no end point for an alarm fatigue reduction project, but there are next steps that need to be completed. Next steps include spreading successful countermeasures throughout the system, creating an administrative committee to formalize the responsibilities of alarm reduction throughout the system, retrying the remote suspension with a comprehensive training about the functionality, implementing the daily electrode change best practice in a telemetry unit and measuring the effects, evaluating electrodes and lead sets for their ability to avoid "ECG Leads Off" alarms and using database analysis to quantify each technology's ability to prevent leads off conditions, and changing the SpO_2 default parameter.

The SpO_2 alarm is the most common alarm in the hospital. One study predicted a 36% decrease in SpO_2 by changing the lower limit from 90% to 85% and a 64% decrease in SpO_2 alarms by changing this limit from 90% to 80% [5]. The reduction in SpO_2 alarms could be a significant countermeasure to eliminate clinically irrelevant alarms.

The Joint Commission (TJC) has released recommendations for combating alarm fatigue [15]. TJC announced the proposed national patient safety goal NPSG.06.01.01 for 2014 that focuses on alarm management [24]. The Elements of Performance (EPs) of the NPSG compliment the findings from this thesis and include:

1) Leaders must establish alarm safety as a hospital priority
2) Prepare annual inventory of alarms used in the hospital and identify default alarm settings
3) Identify the most important alarms to manage
4) Establish policies and procedures for managing alarms
5) Educate staff about alarm policies and procedures

Following the recommendations outlined by the Joint Commission EPs will help complete some of the desired next steps and further sophisticate the alarm reduction program.

5 Conclusion

This thesis recorded the results of several iterations of process improvement. Based on the findings of this thesis it can be concluded that there were many opportunities for reducing clinically irrelevant alarms in the hospital. Unlatching the yellow SpO_2 alarms and a reeducation of telemetry best practices that involved all alarms distributed to all nurse phones were both shown to reduce the total number of clinically irrelevant nuisance alarms. The planned changes to the default adult cardiac telemetry profile, change of the indications and order set for adult cardiac telemetry, change in the SpO_2 monitoring site selection, and change in the ordering of SpO_2 all offer potential reductions in the total number of clinically irrelevant alarms. Alarm suspension from the telemetry pack functionality and a daily electrode change in the neuro-ICU showed no significant reduction in alarms.

There were several limitations to this study including that a subset of the alarms were missing from the database and had to be estimated, the safety of each countermeasure was only analyzed qualitatively and not quantitatively, and observation results were skewed by the observers presence. Alarms that truly require immediate response should be distributed differently than alarms that are not as urgent to reduce the clinically irrelevant noise. Alarms were defined as a signal which requires immediate response and action while an event was defined as an important situation that can be reviewed promptly but retrospectively.

The next steps of the project include spreading successful countermeasures, creating an administrative committee for alarm management, retrying the remote suspension functionality with a comprehensive training, implementing the daily electrode change best practice in a telemetry unit and measuring the effects, evaluating electrodes and lead sets for their ability to avoid “ECG Leads Off” alarms, and changing the SpO_2 default parameter.

The result of these ongoing efforts was a reduction in the count and duration of clinically irrelevant, non-actionable alarms generated and a gradual shift in the culture surrounding monitoring alarms. The work conducted will serve as a roadmap for future process improvement work with patient monitoring systems.

6 References

[1] ECRI Institute, "Top 10 Health Technology Hazards for 2013," *Health Devices*, vol. 41, no. 11, pp. 5-7, November 2012.

[2] ECRI Institute, "Top 10 Health Technology Hazards for 2012," *Health Devices*, vol. 14, no. 11, pp. 4-6, November 2011.

[3] M. Chambrin, P. Ravaux, D. Calvelo-Aros, A. Jaborska, C. Chopin and B. Boniface, "Multicentric Study of Monitoring Alarms in the Adult Intensive Care Unit: A Descriptive Analysis," *Intensive Care Med*, vol. 25, pp. 1360-66, 1999.

[4] AAMI, "Clarion Theme 1: Deepen all stakeholders' understanding of use environments," in *2011 Summit: Clinical Alarms*, 2011.

[5] B. Gross, D. Dahl and L. Nielsen, "Physiologic Monitoring Alarm Load on Medical/Surgical Floors of a Community Hospital," *AAMI Horizons*, vol. Sppring, pp. 29-36, 2011.

[6] M. Cvach, "Monitor Alarm Fatigue: An Integrative Review," *Biomedical Instrumentation & Technology*, no. July/August 2012, pp. 268-77, 2012.

[7] S. Lawless, "Crying wolf: Ffalse alarms in a pediatric intensive care unit," *Critical Care Medicine*, vol. 22, no. 6, pp. 981-5, June 1994.

[8] S. Breznitz, Cry Wolf: The Psychology of False Alarms, Englewood Hills, N. J.: Lawrence Erlbaum Associates, 1984.

[9] Healthcare Technology Foundation, "National Clinical Alarms Survey: Perceptions, Issues, Improvements, and Priorities of Healthcare Professionals," 2011.

[10] L. Kowalczyk, "'Alarm fatigue' a factor in 2nd death," *The Boston Globe,* 21 September 2011.

[11] L. Kowalczyk, "MGH death spurs review of patient monitors," *The Boston Globe,* 21 February 2010.

[12] L. Kowalczyk, "No easy solutions for alarm fatigue," *The Boston Globe,* 14 February 2011.

[13] L. Kowalczyk, "Patient alarms often unheard, unheeded," *The Boston Globe,* 13 February 2011.

[14] Food and Drug Administration, "Alarm Monitoring Problems: Preventing Medical Errors," *FDA Patient Safety News,* January 2011.

[15] The Joint Commission, "Medical device alarm safety in hospitals," *Sentinel Event Alert*, no. 50, 8 April 2013.

[16] Pennsylvania Patient Safety Authority, "Connecting Remote Cardiac Monitoring Issues with Care Areas," *Pennsylvania Patient Safety Advisory,* vol. 6, no. 3, pp. 79-83, September 2009.

[17] Johns Hopkins Hospital, "Using Data to Drive Alarm System Improvement Efforts The Johns Hopkins Hospital Experience," *AAMI Foundation HTSI,* 2012.

[18] M. Vockley, "Plan, Do, Check, Act: Using Action Research to Manage Alarm Systems, Signals, and Responses," AAMI, 2012.

[19] A. Taenzer and G. Blike, "Postoperative Monitoring - The Dartmouth Experience," *Anesthesia Patient Safety Foundation,* no. Spring-Summer 2012, 2012.

[20] J. Welch, "An Evidence-Based Approach to Reduce Nuisance Alarms and Alarm Fatigue," *AAMI Horizons,* no. Spring 2011, pp. 46-52, 2011.

[21] Philips Medical Systems, *IntelliVue Information Center Instructions for Use Release N,* Andover, MA, 2011.

[22] R. Klugman, *Pre-publication; Received in Communication,* 2013.

[23] R. McCarney, J. Warner, S. Iliffe, R. v. Haselen, M. Griffin and P. Fisher, "The Hawthorne Effect: a randomised, controlled trial," *BMC Medical Research Methodology,* vol. 7, no. 30, 2007.

[24] The Joint Commission, "Proposed 2014 National Patient Safety Goal on Alarm Management," *NPSG.06.01.01,* 2013.

[25] A. Taenzer, J. Pyke, S. McGrath and G. Blike, "Defining Normality: Postoperative Heart Rate and SpO2 Distribution of In-Hospital Patients," in *American Anesthesiology Proceedings,* A1466, 2009.

[26] A. Taenzer, J. Pyke and S. McGrath, "Impact of Pulse Oximetry Surveillance on Rescue Events and Intensive Care Unit Transfers," *Anesthesiology,* vol. V, no. 112, pp. 282-287, 2010.

[27] ISO/IEC, *60601-1-8:2006.*

7 Appendix

Table 7-1 Manufacturer Definition of Alarms Types

Severity	Alarm Type	Abbreviation	Philips Definition for Condition Required to Generate Alarm	Current Setting
Critical	Asystole	*** ASYSTOLE	No QRS detected for x seconds.	> 4.0 sec
Critical	Ventricular Fibrillation/Tachycardia	*** V-FIB/TACH	Fibrillatory wave (sinusoidal wave between 2-10 Hz) for 4 consecutive seconds	Enabled
Critical	Ventricular Tachycardia	*** V-TACH	Consecutive PVCs exceed "V-Tach Run Limit" **AND** HR exceeds "V-Tach HR Limit"	V-Tach Run Limit: >= 5 PVCs V-Tach HR Limit: > 100 b/min
Critical	Extreme Tachycardia	***TACHY	Tachycardia limit has been exceeded (either relative limit above current "HR High Limit" **OR** Absolute Max. Tachy Limit)	Relative Limit: 20 b/min > current HR High Limit Absolute Limit: 200 b/min
Critical	Extreme Bradycardia	***BRADY	Bradycardia limit has been exceeded (either relative limit below current "HR Low Limit" **OR** Absolute Min. Brady Limit)	Relative Limit: 20 b/min < current HR Low Limit Absolute Limit: 40 b/min
Critical	Extreme Desaturation	*** DESAT	SpO_2 less than DESAT limit	80%
High Priority	HR High Limit	* HR	Heart Rate greater than the upper HR limit	> 120 b/min
High Priority	HR Low Limit	* HR	Heart Rate lower than the lower HR limit	< 50 b/min
High Priority	Non-Sustain VT	* NON-SUSTAIN VT	A run of ventricular beats having ventricular HR greater than the "V-Tach HR Limit", but lasting for less than the "V-Tach Run Limit"	Enabled
High Priority	Vent Rhythm	* VENT RHYTHM	A dominant rhythm of adjacent ventricular beats greater than "Vent Rhythm Limit" AND ventricular HR less than the "V-Tach HR Limit"	Vent Rhythm Limit: > 14 PVCs

High Priority	Run PVCs	* RUN PVCs	Run of PVCs greater than 2	Enabled > 2 PVCs
High Priority	Pair PVCs	* PAIR PVCs	Two consecutive PVCs between non-PVCs	Enabled
High Priority	R-On-T PVC	* R-ON-T PVC	For HR < 100, a PVC with R-R interval <1/3 the average interval follower by a compensatory pause of 1.25 x average R-R interval or 2 such ventricular beats without a compensatory pause occuring within 5 minutes of each other	Enabled
High Priority	Vent Bigeminy	* VENT BIGEMINY	A dominant rhythm of N, V, N, V (N = supraventricular beat, V = ventricular beat)	Enabled
High Priority	Vent Trigeminy	* VENT TRIGEMINY	A dominant rhythm of N, N, V, N, N, V (N = supraventricular beat, V = ventricular beat)	Enabled
High Priority	PVC Rate (basic)	* PVCs > 10/min	PVCs within one minute exceeded the PVCs /min limit	Enabled >10 PVCs/min
High Priority	Multiform PVC	* MULTIFORM PVCs	The occurrence of two differently shaped ventricular beats, each occurring at least twice within the last 300 beats as well as each occurring at least once within the last 60 beats	Enabled
High Priority	Pacer Not Capture (basic when paced)	* PACER NOT CAPT	No QRS for 1.75 x the average R-R interval with Pace Pulse (paced patient only)	Enabled
High Priority	Pacer Not Pace (basic when paced)	* PACER NOT PACE	No QRS and Pace Pulse for 1.75 x the average R-R interval (paced patient only)	Enabled
High Priority	Pause >	* PAUSE	No QRS detected for x seconds.	Enabled 2.0 seconds
High Priority	Missed Beat	* MISSED BEAT	No beat detected for 1.75 x average R-R interval for HR <120, or no beat for 1 second with HR >120 (non-paced patient only)	Enabled
High Priority	SVT	* SVT	Run of SVPBs >/= SVT Run limit **AND** SVT Heart Rate greater than the SVT HR limit	Enabled >180 b/min
High Priority				Enabled 5 SBVs
High Priority	Irregular HR	* IRREGULAR HR	Consistently irregular rhythm (irregular R-R intervals)	Enabled
High Priority	Low Oxygen Saturation	** SpO2T	Oxygen saturation below SpO_2 limit	90%

Inoperable Condition	ECG Leads Off	ECG LEADS OFF	ECG Leads Removed	Enabled
Inoperable Condition	NO SIGNAL	NO SIGNAL	No Communication with transmitter	Enabled
Inoperable Condition	Replace Transmitter Battery	REPLACE BATTERY T	Low Battery	Enabled
Inoperable Condition	Transmitter Battery Low	BATTERY LOW T	Low Battery	Enabled
Critical	Transmitter Battery Critically Low	!!!REPLACE BATT. T	Low Battery	Enabled

Table 7-2 Sample of Raw Database Information

1/31/2013 12:20:53	A18 A	A18 A: * NON SUSTAIN VT: HR 80 %SpO2T ?
1/31/2013 12:20:55	A18 A	A18 A: *** V-TACH: HR 94 %SpO2T ?
1/31/2013 12:21:04	A16 A	A116 A: ** SPO2T 89 < 90: HR 91 %SpO2T 89
1/31/2013 12:21:46	A61 B	A60 B: REM: ECG LEADS OFF: HR ? %SpO2T ?
1/31/2013 12:21:57	A59 A	A59 A: ** SPO2T 87 < 90: HR 91 %SpO2T 87
1/31/2013 12:22:01	A11 A	A11 A: * NON SUSTAIN VT: HR 112 %SpO2T ?
1/31/2013 12:22:21	A52 A	A52 A: ECG LEADS OFF: HR 93 %SpO2T ?
1/31/2013 12:22:34	A21 A	A21 A: REM: NO SIGNAL:
1/31/2013 12:22:35	A30 A	A30 A: ** SPO2T 86 < 90: HR 82 %SpO2T 87
1/31/2013 12:23:07	A32 A	A32 A: ** SPO2T 87 < 90: HR 80 %SpO2T 87

Table 7-3 Sample of Processed Database Information

DATE	TIME	LABEL	REM?	ALARM_TYPE	CON	LIMIT	T	HR	SpO2
1/31/2013	12:20:53 PM	A18 A	FALSE	* NON SUSTAIN VT				80	
1/31/2013	12:20:55 PM	A18 A	FALSE	*** V-TACH				94	
1/31/2013	12:21:04 PM	A16 A	FALSE	** SPO2T	89	<	90	91	89
1/31/2013	12:21:46 PM	A61 B	TRUE	ECG LEADS OFF					
1/31/2013	12:21:57 PM	A59 A	FALSE	** SPO2T	87	<	90	91	87
1/31/2013	12:22:01 PM	A11 A	FALSE	* NON SUSTAIN VT				112	
1/31/2013	12:22:21 PM	A52 A	FALSE	ECG LEADS OFF				93	
1/31/2013	12:22:34 PM	A21 A	TRUE	NO SIGNAL					
1/31/2013	12:22:35 PM	A30 A	FALSE	** SPO2T	86	<	90	82	87
1/31/2013	12:23:07 PM	A32 A	FALSE	** SPO2T	87	<	90	80	87

Table 7-4 Indications for Initiation and Discontinuation of Cardiac Telemmetry. [22]

Indication for Initiating Monitoring		Indication for Discontinuing Monitoring
Post Cardiac Procedure[1]		
• Pacemaker insertion • Intracardiac defibrillator insertion • Electrophysiologic study (EPS) • PTCA with unstable angina	• Cardiac catheterization[5] • PTCA • Coronary artery stenting • Ablation	• No arrhythmia for 24 hrs • Successful procedure • Successful medical management of arrhythmias
• Low risk • High risk[3]	• No rise in CK in 2 measurements • No EKG changes	
Congestive Heart Failure (CHF)[4]		
• With angina • New dx • Evidence of arrhythmia • Unstable	• Acute • Serum potassium (K) <3.5 • Excessive diuresis	• No MI • No ischemia • No arrhythmia for 24 hrs. • Stable K
Arrhythmia[6]		
• Atrial fibrillation (AF) (New onset or rapid rate) • Ventricular tachycardia (VT) • Other arrhythmia management[8]		• Rate controlled • 24 hrs. after successful cardioversion • After 3 days, clinical judgment • After 3 days of normal sinus rhythm, no arrhythmia in last 48 hrs
Electrolyte Imbalance		
• K<3.2 • K>5.5	• K infusion • Hemodialysis	• Correction of electrolyte imbalance
Following Surgery		
• Post coronary artery bypass graft • Post noncardiac surgery if potentially unsTable[9]		• Clinical judgment • Day 3 and no epicardial wires or arrhythmias
Other		
• Syncope • QT interval > 0.49 seconds • Post cardiac arrest • Post chest trauma[7] • Critical valve disease		• Day 3 if arrhythmia ruled out or negative electrophysiologic study • After 3 days if normal sinus rhythm, no arrhythmia in last 48hrs • Clinical judgment • No arrhythmia for 24 hrs. • Day 3, clinical judgment

1 Not indicated if pt is DNR or negative EPS
2 Not indicated if pain is pleuritic, positional, or palpable
3 Not indicated if VT or VF < 48hrs of MI
4 Not indicated for stable CHF
5 Not indicated for routine, uncomplicated coronary artery catheterization
6 Not indicated for chronic AF, AF with controlled rate, or asymptomatic AF.
7 Not indicated if ECG is normal
8 Not indicated for stable premature ventricular contractions
9 Not indicated for low-risk post-operative patients

(Received in communication [22])